Deepwater Habitat and Fish Resources Associated with a Marine Reserve: Implications for Fisheries

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Technical Narrative

Abstract

Big Creek Ecological Research Reserve (BCER), located off the Big Sur coast, has been closed to fishing since January 1994. We combined the use of sidescan sonar, bottom profiling, and occupied submersible operations to identify and characterize large- (i.e., 100s of meters to kilometers) and small-scale (i.e., 1 meter to 10s of meters) habitats and associated benthic fish resources in deep water inside and adjacent to BCER. Our objectives were to estimate species-habitat relationships, abundance (measured as density: number of fish per habitat-specific area), and species and size composition of fish assemblages, and to compare these variables inside and outside the reserve and between two years of increased protection.

We completed two field seasons of data collection in October 1997 and September 1998. Forty-five research dives were made in water depths from 20–250 m inside and outside BCER, during which 142 10-min video transect surveys of fishes and associated habitats were completed over various bottom types. In total, 70,094 individual fishes were identified from 82 taxa, including 36 species of rockfishes. About 93% of the 25,159 fishes counted inside BCER were rockfishes comprising at least 20 species. Several distinct fish assemblages have been described in general. Young-of-the-year (YOY) rockfishes dominated rock outcrops of 20–90 m depth both inside and outside BCER—they were rarely observed at deeper water depths. Shallow (<35 m depth) assemblages of adult fishes were more diverse over rock than sand; diversity was higher in deep water than in shallow water.

Canonical correlation analysis of density constrained by habitat revealed distinct assemblages associated with (1) fine smooth sediment in deep water; (2) bedrock habitats with uneven surface in deep water; (3) sand waves and shell hash in shallow water; and (4) boulders and organic habitats on rock in shallow water. From Analyses of Variance, we tested for differences of fish density inside and outside BCER, with year, depth, and substratum types as factors. There was higher fish density consistently in high relief rock habitats. There was no significant difference in fish density inside and outside BCER, among depths, or between years. Our statistical power to detect differences in density among locations was low, with an insufficient number of samples per

cell to discern the differences. For seven economically valuable species, there were no clear patterns of larger total size inside the protected area.

Our primary recommendation is to develop a monitoring program to continue these surveys after increased time of protection and with increased assessment effort in the appropriate habitats of the economically valuable species (that is, the high relief rock substrata with associated rockfish species).

Introduction

Multi-species rockfish (*Sebastes*) resources have been among the most economically valuable commercial and recreational fisheries along the West Coast of North America for the last two decades, and historically have represented a mainstay of many coastal communities. For instance, many of the 60 species of rockfish in California waters have been commercially harvested from as early as 1875 (Phillips 1939; 1957; Deimling and Liss 1994). While rockfish landings and effort off California in particular have increased dramatically over the last 40 years (Lea 1992), abundance and size composition have decreased for several species (Pearson and Ralston 1990; Mason 1995; 1998; Ralston 1998). Recent stock assessments indicate long-term declines in biomass for several rockfish species and lingcod (*Ophiodon elongatus*) off California, Oregon and Washington (Ralston 1998; Adams et al. 1999; MacCall et al. 1999). Such downward trends in biomass likely are due to natural variability in the marine environment and the resultant levels of survival of young fish, as well as the fishing-down of stocks that previously were lightly exploited. However, biomass of many rockfish species now is estimated to be 20% or much less of the estimated population size of 30 or more years ago. Exploitable biomass and spawning biomass of the bocaccio (*S. paucispinis*) population off Central and Northern California, for example, are now 2–4% of that estimated in the mid-1960s (MacCall 1999). Clearly, past management efforts alone have not successfully protected and sustained many of our coastal fish populations and their habitats.

Marine reserves (also known as no-take areas, marine protected or managed areas, harvest refugia) are being considered as a supplement to traditional resource management practices throughout the world (Rowley 1994; Yoklavich 1998; Murray et al. 1999; Parrish et al. 2000). Reserves serve as undisturbed areas for research on natural populations and as fishery exclusion zones where fishes take refuge from exploitation. Marine protected areas (MPAs) have demonstrably enhanced fish populations within their borders by: (1) increasing fish abundance, size, and reproductive output; (2) protecting critical spawning stocks and habitats; and (3) providing multi-species protection (Dugan and Davis 1993; Halpern 2000; Murawski et al. 2000). In addition, marine reserves may help in conserving marine biological diversity, a topic that has received significant national and international attention, with fisheries identified as one of the most critical environmental threats to biodiversity (Boehlert 1996; Bohnsack and Ault 1996). Unharvested areas also could provide the means to separate the effects that fishing and other human activities have on fish populations from the effects caused by natural changes in the environment. While not as well documented, it also has been suggested that reserves could serve as sources of replenishment to fisheries in unprotected nearby areas.

Designated no-take reserves (those that prohibit the harvest of all species) are uncommon along the West Coast. Most of these reserves were established for general conservation purposes, without the specific objective of effective fisheries and ecosystem management. Monitoring biological resources in many of these small areas has just begun. There are 17 tiny marine reserves off California that prohibit either recreational, commercial, or all harvest. These areas cover a total of 32 km of coastline and comprise a mere 44 km^2 or 0.26% of state waters (McArdle 1997; 1998). Off Washington, there are four small reserves in Puget Sound that prohibit recreational and commercial bottom-fishing. These areas range in size from 0.002 to 5.5 km^2 (Palsson 1998). Off Oregon, there is only one tiny marine reserve that is closed to taking fishes and invertebrates and is located in Whale Cove along the central Oregon coast (Didier 1998). There are no marine reserves in water deeper than 100 meters anywhere off the West Coast.

There is growing empirical evidence that some fish species protected within some of the few existing no-take marine reserves on the West Coast have greater abundance and size, and consequently increased spawning biomass, compared with those in adjacent fished areas. For example, reproductive potential of copper rockfish inside a 27-year-old marine reserve in shallow water of Puget Sound, Washington, was 55 times greater than that of coppers subject to heavy fishing pressure outside the reserve (Palsson 1998). This enhanced reproductive potential derived from greater densities and larger sizes of coppers inside the reserve. Similarly, significantly more and larger lingcod and copper rockfish were observed inside a tiny 6-year-old no-take reserve in the San Juan Islands, Washington, compared to adjacent unprotected areas (Palsson and Pacunski 1995). Reproductive potential for black-and-yellow and kelp rockfishes inside two small longtime reserves in the Monterey Bay, California, area was greater than that for these species in heavily fished areas immediately outside the reserves (Paddack and Estes 2000). Despite their small size and lack of scientific siting criteria, some of the West Coast reserves that have been studied thus far exhibit significant increases in abundance, size, or reproductive capacity of exploited species.

Similarly, enhanced abundance and size have been reported for species associated with natural refugia (i.e., those areas that naturally afford protection from fishing) and other unintentional reserves. Examples include refuge for a healthy red abalone population off Northern California at water depths that preclude harvest (Tegner et al. 1992), and high numbers of large rockfishes locally associated with isolated rock outcrops in deep water of narrow submarine canyons that are less accessible to fishing (Yoklavich et al. 2000).

Restricted fishing access for security reasons at of the Kennedy Space Center at Cape Canaveral over the last two decades has resulted in greater diversity, density and size of economically valuable fishes in two unfished areas compared to nearby fished areas; tagging studies demonstrated movement of fishes from the de facto reserves to the fished areas (Bohnsack 1998; Johnson et al. 1999). It seems clear that the portion of a population protected from the effects of fishery selection will live longer, achieve larger sizes and a more natural size distribution, and, therefore, produce more young over their lifetime than counterparts in unprotected fished areas.

Fishery reserves are considered to be beneficial to those species that are overfished, reach great sizes or ages, and have limited movements or sedentary behavior; the life history characteristics and status of stocks of many rockfish species meet these criteria. Rockfishes are tremendously diverse (about 102 species worldwide and at least 72 species in the northeastern Pacific [Kendall 1991]), and range in maximum size from 18 and 23 cm for dwarf species such as Puget Sound and pygmy rockfishes to 94 and 120 cm for the largest species like cowcod and shortraker rockfish (Love et al. 2002). Rockfishes are found from intertidal depths to over 700 m, and can dominate coastal marine habitats from subtidal kelp forests to rock outcrops in submarine canyons. Many species of rockfish are slow-growing, long-lived (50–205 yrs [Archibald et al. 1981; Munk 2001]), and mature at older ages (6–12 yrs [Wyllie Echeverria 1987]). Survival and subsequent recruitment of young rockfishes vary widely from year to year, and are linked to environmental factors (Ralston and Howard 1995). It is likely that an outstanding year class may occur only once in 20 or more years; for example, the last strong year class for bocaccio was 1977, which in turn has been harvested since the early 1980s. Rockfishes generally have relatively low mobility and many species are considered to be sedentary once they settle to adult habitats. While this unique set of life history characteristics makes rockfishes particularly vulnerable to overfishing, it also renders them amenable to protection by marine reserves.

The Big Creek Ecological Reserve, established on the Central California coast and closed to fishing since January 1994, affords the opportunity to collect baseline information on fish species composition, density, and size and initiate an evaluation of some of the benefits of reserves to rockfishes. Rockfishes are important to the nearshore community off Big Creek, as well as elsewhere on the central coast. Several species are a significant part of a relatively new live-fish fishery, which occurs in water as shallow as three feet off the central coast. Since 1989, there has been an order of magnitude increase in the number of fishermen and vessels in this fishery in California (T. Barnes, California Department of Fish and Game [CDFG], unpublished data). Annual catch has increased dramatically, from essentially zero in 1989, to almost 500,000 pounds in 1996.

Rockfish species have affinities for specific seafloor substrata, the type and extent of which can help determine species distribution, abundance, and richness (Richards 1986; Pearcy et al. 1989; Stein et al. 1992; Yoklavich et al. 2000). Studies of marine fish assemblages and their habitats are limited by available technology. Most studies on habitat specificity of rockfishes have been conducted in shallow water (Larson 1980; Carr 1991, among others), where sampling and surveying are much easier to perform than in deep ocean environments. In recent years a foundation for a systematic approach to characterize marine habitats and fish assemblages has been developed in deep water (i.e., >25 m). The relationship between these assemblages and habitats has been delineated using in situ methodologies via an occupied submersible and remote geophysical mapping techniques. We have applied this approach to studying the distribution and habitat specificity of marine benthic fishes in deep water off Alaska, Oregon, and Central California. With funding from NOAA's National Undersea Research Program (NURP), our team of marine biologists and geologists evaluated the function of submarine canyons in the Monterey Bay area as natural refuges from fishing for benthic fishes (Yoklavich et al. 2000). We characterized habitats that support adult rockfishes in deep water on mega- (kilometers) to macro-scales (meters), and compared abundance, size, and fine-scale distribution and habitat specificity for rockfishes at both lightly- and heavily-fished sites. Rockfish species were habitat specific, and species richness was highest at sites with complex rock habitat. Although appropriate habitat was available in areas of heavy fishing, there were fewer individuals of large species, smaller sizes of large species, and different species composition as compared to areas that receive less fishing pressure. We suggested that assemblages of large species of rockfishes associated with deep isolated outcrops on steep slopes are likely protected from excessive harvest because habitat characteristics make them difficult to target. These results from areas of natural refugia have application in evaluating the benefits of marine harvest reserves, as well as understanding associations between fishes and habitat in areas that have been difficult to evaluate using traditional methods. Characterizing and quantifying elements of available habitat, such as substrata type and water depth, and the association of habitat to fish assemblages are critical in evaluating the effectiveness of BCER in maintaining regional rockfish resources.

Goals and Objectives

The overall goals during the first two years of our research were to gather baseline information on fishes and habitats from which to inventory and describe these resources in deep water of BCER, and to learn more about the value of BCER to fisheries management. This information will be useful when evaluating future changes to BCER populations of benthic fishes in deep water, and is complementary to the long-term research program currently being conducted by CDFG on shallow-water fishery resources in BCER. It will also be critical to the assessment of populations of nearshore species, as required in the CDFG's new nearshore management plan.

We asked the general question: What benthic habitats and fish species occur at water depths 20–250 m in the vicinity of BCER? More specifically we asked what differences occur in abundance (measured as density: number of fish per habitat-specific area), species-habitat relationships, and size structure of benthic fishes in deep water inside the reserve as compared to the adjacent unprotected areas. Toward meeting these goals we set the following objectives:

1) To verify (groundtruth) our interpretations of seafloor substrata made from sidescan sonar images collected during a previous geophysical survey of this area;
2) To provide estimates of relative abundance and distribution of seafloor habitats in the study area;
3) To quantify fish density, size structure, species composition and richness, relative to depth and substrata in deep water of BCER and adjacent unprotected areas;
4) To compare these variables (from No. 3) between two years of increasing resource protection;
5) To test the null hypothesis that there is no difference in fish assemblages (numbers and sizes) between BCER and adjacent unprotected areas;
6) To provide accurate maps of species-habitat relationships within study areas; and
7) To produce a comprehensive data set of fish species, abundance, size, and habitat associations.

Methods

Study Site

The Big Creek Ecological Reserve is about 8 km^2 in area, located within the Monterey Bay National Marine Sanctuary (MBNMS), and about 90 km south of Monterey (Figure 1). This reserve has been closed completely to harvest activity since January 1994. It is contiguous with the University of California Landels-Hill Big Creek Reserve, which protects about 16 km^2 of coastal terrestrial habitats. The boundary of BCER extends for 4.5 km along the coast from 36° 05.31' N and 121° 37' W to 36° 03.65' N and 121° 35.6' W, and due west offshore to about 100 m water depth. Our study was conducted inside BCER at water depths of 20–100 m, as well as in areas adjacent to BCER at similar depths (Figure 2a–d); these areas comprised 4.8 km^2 inside the reserve, 7.6 km^2 to the north, and 7.4 km^2 to the south. We also surveyed fishes and habitats in about 4.8 km^2 seaward of these three areas at water depths from 100 to 250 m.

Our study area is situated on a relatively narrow part of the continental shelf, which continues into numerous steep submarine canyons along the continental slope. Exposed bedrock and terrestrially derived coarse sediment (e.g., boulders, cobbles, and pebbles) are found both on the shelf and in the channels and canyons of the continental slope. Much of the coarse-grained sediment is supplied onto the shelf by the many high-gradient creeks that incise the Santa Lucia Mountains and by coastal landslides in the region; it is likely that some of this material is transported across the shelf to the continental slope (Yoklavich et al. 1997). Much of the shelf is covered with sand (in approx. <100 m water depth) and fine sediment (in approx. >100 m).

Verification, Distribution, and Abundance of Seafloor Substrata

We completed a sidescan sonar survey of seafloor substrata in BCER and adjacent study areas during June 3–5, 1996 onboard the NOAA ship *McArthur* with funding from NOAA MBNMS (Yoklavich et al. 1997). A map of substrata types, ranging from rock outcrop to soft sand and fine sediments, was produced from these sonographs using MapGraphics geographical information system (GIS). During our MERRP-funded research we verified our interpretations of this map by direct observations made from the *Delta* submersible. Observations along each dive track were positioned precisely with navigational data from a differential global positioning system (GPS). The map of seafloor substrata was revised to reflect these observations. We used this map to quantify the amount of various types of substrata that occurred within the study areas.

Fish and Habitat Surveys

Methodologies to assess benthic fishes and associated habitats in the BCER study areas were similar to those used previously during surveys of deep-water fishes and habitats in submarine canyons (Yoklavich et al. 1993; 2000). We used the *Delta* submersible (Figure 3) from the support vessel R/V *Cavalier* during September 29–October 4, 1997, and from the R/V *McGaw* during September 20–25, 1998. The *Delta* is a small (4.75 m) submersible, accommodates one scientific observer and a pilot, has a maximum operating depth of 365 m, and a cruising speed of 1.5 knots. An acoustic track-point system and GPS were used onboard the support vessel to record the underwater location of the submersible.

Dives were made only in fall, the time of year yielding the best opportunity for calm seas in our region. All dives were made during daylight (between about 1 h after sunrise and 2 h prior to sunset) to avoid bias due to potential diel activity patterns of some species. Dives were 1–2 h duration, and were conducted in 23–276 m water depth. All dives were documented continuously with an externally mounted high-8 mm video camera and associated lights that were externally mounted on the starboard side of the submersible. To quantify fish abundance and habitat associations, we conducted 1–4 10-min strip transects during each dive, about 1–2 m off the seafloor at 0.5–1.0 knots. We used the maps of seafloor habitats from our previous sidescan sonar survey to locate dive sites in various depths and substratum types, inside, north, south, and west of BCER. Videotapes were verbally annotated by the scientific observer, who identified, counted, and estimated size of all fishes within a 2-m strip in front of the starboard viewing port; this was the same viewing field as recorded with the video camera. We occasionally used a hand-held dive sonar from inside the submersible to estimate distance from the observer to large objects (rocks or fishes); this helped us calibrate the width of the transect strip. We duplicated verbal annotations with a hand-held voice recorder. A digital video camera was used occasionally from inside the submersible to facilitate species identifications. All divers debriefed after their dives (either onboard the support vessel or in the laboratory), which included transcribing observations on fishes and habitat from audio and video tapes into a digital data set. Each record in the data set includes dive number, time of observation (later cross-linked to navigation data), fish identification to lowest possible taxon, estimated total length of fish (if possible), associated habitat or substratum type (see description below), and water depth.

Two parallel lasers were installed on either side of the external video camera at a fixed distance of 20 cm apart (Figure 3). The laser spots were projected onto the seafloor, and were visible to the observer and recorded onto the videotape. The lasers were critical for estimating fish size and distance traveled during each transect. We made measurements by comparing the size of a fish or habitat feature to the known spacing of the two bright laser spots when the object was perpendicular to the camera and lasers (Tusting and Davis 1993; Yoklavich et al. 2000). We estimated the length of each transect, independent of submersible speed and bottom currents and type, by counting the number of laser spot intervals as they moved along the seafloor in the video transect (similar to using a yardstick, end over end along the transect).

The type of substratum associated with each fish in the transect was characterized from the videotapes; these types included boulder, rock outcrop, vertical rock pinnacle, cobble, sand, hash, organic (e.g., understory algae), and fine sediment, as described by Greene et al. (1999). Secondarily, surface morphology also was described as either smooth, uneven (i.e., sediment, rock, or organic substrata types with holes, pockets, depressions, caves, crevices, ledges, rugose, and heteromorphic features), and sediment waves and ripples.

Various combinations of substrata were categorized according to primary (at least 50% of the area viewed) and secondary (>20% of the area viewed), following the protocol of Stein et al. (1992) and Yoklavich et al. (2000). Area of each substratum combination (referred to as a habitat patch) along a transect was quantified. Species-specific abundance was standardized per area of associated substratum (i.e., density: number of fish per m^2 of each habitat patch).

Data Analyses

Canonical correlation analysis was used to identify patterns in associations among fishes and characteristics of their habitat. This analysis uses a matrix benthic fishes in relation to microhabitat. Only species occurring in at least 5% of the habitat patches were considered, thereby eliminating rare species from this particular analysis. Only nonschooling (i.e., nonpolarized aggregations or solitary individuals) benthic fishes were included in our analyses; unidentified YOY rockfishes were not included in these analyses. In this analysis we viewed "year"(that is 1997 and 1998) as a covariate; its effect was removed by using a partial canonical correlation to best describe the fish-habitat associations.

Further analyses were focused on comparisons of fish density (number of fishes per 100 m^2 of habitat type) among location (inside, north, and south of the reserve), habitat type (a priori we defined as three groups of habitat types: (1) low relief soft sediments of primarily shell hash and sand; (2) low relief mixed sediments of cobbles, organic understory, sand, hash, flat rock; and (3) high relief rock substratum primarily comprising boulders and rock outcrop), water depth (<35 m, 35–100 m, 100–135 m, and >135 m), and year (1997 and 1998). We used Analysis of Variance (ANOVA) with balanced design and data transformation where appropriate to meet assumptions of tests. We used Tukey Post Hoc Multiple Comparisons of cell means with Kramer's modification to identify specific locations, habitat types, depth, or year that contributed to significant factors in the models. We estimated effect size using a power analysis, from which we evaluated our ability to detect a difference among factors in our analyses.

Overall species diversity for 15 discrete areas, as identified by depth and various substrata types on the habitat map of the study site, was calculated as

$$H' = \sum_{i=1}^{s} [p_i][1 \mathrm{n} p_i]$$

where s = number of species and p_i = proportional abundance of species i. Richness (number of species) and evenness ($J' = H'/H'_{max}$) also were calculated.

Results

We completed two field seasons of data collection using the submersible *Delta* in October 1997 and September 1998. Fifty-three submersible dives were made inside and outside BCER. A total of 142 10-min video transect surveys (Table 1) of fishes and associated habitats was completed over various bottom types and water depths during 45 dives (Figure 2b–d). Thirty-nine transects were conducted inside the reserve during both years; the rest were conducted outside the reserve to the north, south, and west for comparison of fish densities, diversity, and sizes. The remaining 10 dives were for pilot training (1), geological observations (4), public relations (2), and equipment malfunction (3).

Objectives 1 and 2

Verification, Distribution, and Abundance of Seafloor Substrata

From submersible observations, we verified our interpretation of 24.6 km^2 of seafloor that was surveyed previously using sidescan sonar inside and adjacent to BCER, and modified existing maps to accurately reflect substrata types in 20–250 m water depth (Figure 2a–d). We identified and quantified seven substratum types: sediment (both fine and coarse, with grain size <0.06 mm); sand (0.06–2 mm diameter); sediment waves (Figure 4a, b) and ripples; isolated boulders (>0.25 m diameter); pinnacles (Figure 4d); rock outcrop (Figure 4c, e, f); and a matrix of rock outcrop, boulder, cobble, and sediment.

Sand substratum of low relief was located almost entirely on the shelf in water depths <100 m; sand represented 64% of the seafloor types within the reserve (Table 2; Figure 5). We could not distinguish fine and coarse sediments from the sidescan sonar images, but our observations from the submersible revealed that fine sediment typically occurred at water depths >100 m and coarse sediments were found at depths <100 m. We selected the 100-m isobath to differentiate fine from coarse sediments on our seafloor maps (unless submersible observations suggested otherwise). Sediment was distinct from sand substratum in both the sidescan sonar and video images. Ninety percent of the seafloor in water depth >100 m was identified as fine sediment. Sediment ripples were clearly identified in both sonographs and video images. We located areas of ripples and waves over sand and sediment; 3% of substratum types inside BCER comprised sand waves and ripples. The distribution of some substratum types, especially fine sediments and sediment ripples, likely changes over time because of seasonal wave, current and tidal energy and terrestrial-influenced sedimentation.

Complex substratum types of relatively high relief (e.g., boulders, pinnacles, rock outcrop, and the matrix of rock/sediment) comprised about 12.8% of the 4.8 km^2 of seafloor that were surveyed inside the reserve (Table 2; Figure 5; see examples in Figure 4c–d). Similar proportions of complex rock bottom types were represented in our study areas to the north (8.9%) and south (10.3%) of the reserve at the same water depth. Relatively greater amounts of boulders and mixed rock and sediment were found to the south. Complex rock outcrop and boulders comprised about 6.4% of the seafloor substratum types in water depths >100 m and were found exclusively in the heads of submarine canyons outside BCER (see Figure 4e–f for examples).

We identified 45 isolated pinnacles, large boulders, and outcrops from the sonographs and in situ observations from the submersible (Figure 2b–d; see example in Figure 4d). These isolated features ranged from 5–22 m in height and 8–126 m in width. Most of these features were associated with either the matrix of rock and sediment or larger rock outcrops on the shelf in <100 m water depth. A few were surrounded by sand or coarse sediment substrata. Nine of these features were identified within the reserve, nine in the area to the south of the reserve, and 27 pinnacles and large boulders were located to the north of the reserve.

Objectives 3 – 7

Quantify fish density, size, species composition and richness, relative to depth and substrata in deep water of BCER and adjacent unprotected areas

A total of 70,094 individual fishes from 82 taxa (see Appendix 1 for both scientific and common names) was identified from all video transects conducted inside (Table 3a) and outside BCER (Table 3b, c) during the two years of study. These included a minimum of 36 species of rockfishes. About 93% of the 25,159 fishes (representing 49 taxa) counted inside BCER were rockfishes comprising at least 20 species. From those transects conducted at similar water depths (i.e., <100 m), in general there was greater number of fish and rockfish species inside and to the north of BCER compared to the assemblage surveyed to the south of the reserve (Table 3a, b). From 30 to 82% of the fishes surveyed in water depths <100 m, both in and out of BCER, were Young-of-the-Year (YOY) rockfishes. We were unable to identify most of these YOY to species. Young-of-the-Year represented only 0.7–1.9% of the total number of fishes counted in water depths >100m.

The most abundant rockfishes (>0.1% of total number of fishes) inside the reserve in both years included halfbanded, blue, pygmy, olive, and gopher rockfishes; bocaccio and shortbelly, copper and rosy rockfishes were relatively abundant (>0.1% of total number of fishes) only in 1998. Relatively abundant nonrockfish species inside the reserve included speckled and Pacific sanddabs, blackeye goby, and painted greenling. Similar species were relatively abundant outside the reserve to the north at depths <100 m (i.e., halfbanded, blue, pygmy, olive, gopher, copper, and rosy rockfishes), as well as widow, squarespot, and vermilion rockfishes. While far fewer fishes and species were surveyed to the south of the reserve at similar depths, species composition was similar.

The canonical correlation analysis of fish density constrained by habitat (substrata, surface morphology, depth) data revealed a primary separation of species by depth (Figure 6; axis 1, accounting for 62% of the total variance) and a secondary separation of species based on combinations of substrata type, surface morphology, and degree of slope (axis 2, accounting for 16% of the variance). All species to the right of the vertical line (Figure 6a) occur in relatively deep water (i.e., depth gradient is increasing as you move to the right from center point [Figure 6b]). There are basically two deepwater groups (the two quadrants on the ordination) within the deepwater assemblage: (1) Dover sole, rex sole, unidentified poachers, slender sole, and Pacific hake are found on deep smooth fine sediment; unidentified flatfishes also are found on smooth fine sediments of various depths; (2) the rockfishes (rosethorn, greenspotted, bank, yelloweye, squarespot, and darkblotched) occur in relatively deep, sloping habitats primarily comprising bedrock and some cobble with uneven surface morphology (e.g., having crevices, ledges, etc.). In addition, pygmy rockfish stand out as an idiosyncratic species that also is related to deep rock habitats with uneven surfaces. Stripetail, sharpchin, and greenstriped rockfishes occur in the deepwater assemblage, but are not strictly associated with either rock or fine sediments.

Within the relatively shallow fauna, there also are two groups: (1) Speckled and Pacific sanddabs and unidentified sculpins, found on sand waves and ripples and shell hash; (2) the rockfishes (olive, blue, gopher, rosy, copper, vermilion, and halfbanded), painted greenling, blackeye goby, sharpnose surfperch, and señorita, associated with boulders and organic habitats (such as kelp and understory algae) that overlay rock outcrop.

Based on these primary (depth) and secondary (substratum type) habitat characteristics, the seafloor along each transect was categorized for further analyses using three general types of habitats: high relief rock (primarily including various combinations of boulders and outcrop); low relief mixed sediments (including cobbles, organic understory, and flat rock mixed with various amounts of sand and hash); and low relief sediment (primarily sand, hash, or fine sediment). The amount of area covered and distribution of these general habitats varied along each transect on a scale of meters (see example in Figure 7).

Relative percent of each of these general habitat types that was surveyed during our quantitative transects varied by depth and location (inside BCER, and to the north, south, and west of BCER; Figure 8 and Table 4). Overall we visually surveyed 13,901 m^2 of seafloor inside the reserve during 1997–98, and 15,373 and 7,410 m^2 to the north and south of BCER, respectively. While the relative percent of low relief soft sediment was generally high in these surveys, we tried to focus effort in the complex habitats with high species density and diversity. Low relief mixed sediment habitat of cobbles, sand, hash, and organics in various proportions occurred to a lesser amount in the study area and consequently was surveyed to a lesser extent than the other two categories. In deeper water outside the reserve, we surveyed mostly high relief rock habitat and low relief soft sediment (Figure 8).

Fifteen discrete areas were identified by depth and various substrata types (rock outcrop, sand, pinnacle, etc.) on the habitat map of the entire study site (Figure 9). In each area and year, density (number of fish per area surveyed per 100 m^2) was calculated for each fish species associated with soft sediment habitat and low and high relief rock/mixed habitat. Young-of-the-year rockfish abundance was not included in these estimates of density. Densities were averaged over both years and displayed on the habitat map for the entire study area (Figure 9a–d). Species richness, diversity, and evenness also were calculated from these estimates of species densities. Overall fish density was higher over rock substrata than over sand and fine sediments. The shallow-water assemblages in general were more diverse over rock outcrops than over sand. Some of the shallow water assemblages were dominated by a one or two species (e.g., blue rockfish on shallow pinnacles or outcrops and sanddabs over shallow sand areas), which resulted in low evenness indices. In general, diversity was higher in deep-water assemblages than in shallow water.

Most YOY rockfishes were not identified to species and were difficult to count. From estimates of their density during the quantitative transects (Figure 10), young rockfishes dominated fish assemblages on the relatively shallow (20–90 m) rock outcrops and pinnacles (especially sites no. 1, 2, 9, 11, 12 and 15), both inside and outside the reserve. Young-of-the-year density at those sites ranged from 27 to 857 YOY per 100 m^2 and 38–93% of all fishes on the outcrops. Low-relief fields of coarse sand and sea pens in about 70 m of water (e.g., site 12) appeared to be a nursery ground for stripetail rockfish in particular (one of the few species that were identified). Young-of-the-year were rarely, if ever, observed in deep water.

Comparing Fish Densities among BCER and Adjacent Unprotected Areas

To test the null hypothesis that there is no difference in fish density inside BCER and in adjacent unprotected areas, we conducted several analyses of variance (ANOVA). First, we compared total fish densities in 1997 among two depth categories (<35 m and 35–100 m), three substrata categories (low relief soft sediment, low relief mixed, and high relief rock), and three locations (north, inside, and south of the reserve). We did not include data from 1998 in this analysis because we did not have an orthogonal sample design; that is, depth was not represented in all combinations of the other factors. All species were used in this comparison of total fish density, with the following exceptions: species that were particularly mobile and difficult to accurately count (i.e., tubesnout, Pacific saury, Pacific hake, Pacific argentine, YOY rockfishes, and shortbelly rockfish).

In this first ANOVA, there was a significant difference in fish density among the three substrata types (Table 5). The Tukey Post Hoc Multiple Comparison Test revealed a significant difference in fish density between the high relief rock category and the low relief soft and mixed categories; densities in soft and mixed substrata were not significantly different. There was no significant difference in total fish density among locations or depths. There were no significant interactions between or among the factors (Table 5). Total fish density was significantly greater in rock habitat than in the other two low relief habitats, and this pattern applied to both depth categories and all three locations (Figure 11).

We tested our ability to detect a difference among locations (i.e., north, inside, and south of the reserve) using a power analysis. Populations with small differences (or effect size) will have lower power to detect the difference, therefore requiring greater sample size. From this analysis we had a power level of 8%, with 24 samples per cell; this means we had a 92% chance that we incorrectly accepted the null hypothesis that there was no difference in fish density among locations. The sample size needed for 80% power of detection is calculated to be 503 samples per location. The recommendation would be to increase sampling effort in the habitats with the highest densities (that is, concentrate on increasing the number of samples in the high relief rock habitats in all three locations in order to reduce variability).

In a second ANOVA to assess differences in density with increasing years of protection, we compared total fish densities at one depth (35–100 m) among years (1997 and 1998), substrata, and locations. Both depth categories were not used in this comparison because the shallow depth category (<35 m) was not represented in all combinations of the other factors. Again, the only significant difference among main factors was that of substrata (Table 6), with high relief rock having greater densities than low relief mixed and soft sediments; fish density in low relief mixed habitat was greater than that in low relief soft (Figure 12). These differences in density with substrata were confounded by the year and location factors (i.e., significant interaction terms; Table 6); this was largely due to the high densities of fish (notably halfbanded rockfishes) in 1998 in high relief rock inside and north of the reserve (Figure 12). There were no significant differences in fish densities among locations and years (Table 6). From a power analysis, we had insufficient ability to detect a difference among locations. There was a 61% chance that we incorrectly accepted the null hypothesis that there was no difference in density among locations; with 73 samples per cell, our power was 39%. Our recommendation is to increase sampling effort in those habitats of most interest (e.g., high relief rock), and repeat this survey and comparison between years and locations following increased time of protection.

In a third ANOVA, we compared densities of just those fish of commercial and recreational economic value, including rockfishes (blue, olive, vermilion, canary, gopher, copper, and yellowtail) and lingcod, that occurred on high relief rock substrata among locations (north, inside, and south of the reserve) and years (1997 and 1998). There were significant differences in fish density between years, with higher adjusted least square mean density in 1997 than 1998 (Table 7). Interestingly, the declines in mean densities from 1997 to 1998 were greatest in both areas outside the reserve; mean density of economic species in 1998 was greater in the reserve than outside (Figure 13). No differences in density were found among locations and there were no significant interaction terms. Our power to detect a difference in density among locations was low (12%), with an insufficient number (39) of samples per cell to discern the difference. Again, the recommendation would be to continue these surveys after increased time of protection and with increased assessment effort in the appropriate habitats of these economically valuable species (that is, the high relief rock substrata).

Comparing Fish Sizes among BCER and Adjacent Unprotected Areas

In addition to densities of fishes, we also examined the size frequency distributions of seven economically valuable species (lingcod, and blue, rosy, olive, copper, gopher, and vermilion rockfishes) that occurred in water of 20–100 m, inside and outside the reserve during each year of our surveys. Because there was a statistical difference in size of blue rockfishes between shallow (<35 m) and deep (35–100 m) water, we analyzed size distributions from these two depth strata separately. We used a Kolmogorov-Smirnov goodness of fit test to compare size distributions inside and outside the reserve in each year for each species.

For most of the species, there were no clear patterns of larger sizes inside the protected area. Size distributions likely reflect magnitude of recruitment of young fishes in a given year and place, movement of fishes at various sizes, as well as any potential effect of increased protection. The size distributions of blue rockfish were significantly different inside and outside the reserve, in both years and both depth strata (see significant p-values, Figure 14). However, it was only in deep water in 1998 (Figure 14b) that sizes were skewed toward larger fish inside the reserve (i.e, in 1998, 50% of 134 blues were 30 cm total length inside the reserve compared to zero fish of that size outside).

Size distributions of olive rockfish also differed significantly in and out of the reserve in both years (see p-values, Figure 15a). In 1997, the population outside the reserve was skewed toward larger size classes (>30 cm) compared to inside. However, this pattern was reversed in 1998, with the largest size classes (>35 cm) being truncated in the size distribution of olives outside the reserve. There was no significant difference in the size structure of gopher rockfish in and out of the reserve in either 1997 or 1998 (Figure 15b).

Comparisons of size distributions could not be made for copper, vermilion and rosy rockfishes in 1997 because of low sample sizes of estimated lengths inside the reserve (Figure 16a and b; Figure 17 b). Distributions of rosy and vermilion rockfishes in 1998 were not significantly different in and out of the reserve, and the largest vermilion occurred in the outside surveys (Figure 16b). Lingcod size distributions were statistically similar in and out of the reserve in both years (Figure 17a).

Summary

We accomplished all our planned objectives for this project. Using *in situ* video methods from an occupied submersible was an effective method to verify (or groundtruth) and characterize benthic habitats of the BCER and adjacent areas on a spatial scale (i.e., microscale of < 1 m to macroscale of 1–10 m) relevant to associated fish species. Our results indicated that seafloor substratum types were not uniformly distributed within the reserve, nor were they equal in relative abundance. Big Creek Ecological Reserve encompasses a small, relatively flat area of the shelf and contains seafloor habitats that primarily comprise sand and sand waves/ripples with patches of complex rock outcrop of high relief in water depths <50 m. Some isolated pinnacles, smaller outcrops, and boulders are found in the deep parts of the reserve. Substantial amounts of high relief rock outcrop habitat also are located outside the in deep-water heads of offshore canyons. To preserve all representative types of habitats in the study area, protection within BCER should be extended offshore to include deep-water complex habitats and north and south to encompass more of the high relief rock patches of habitat that are in short supply throughout the area.

Similarly, the assemblages of fish species associated with these various benthic habitats varied with depth and habitat type throughout our study area. The shallow high relief rock habitat, while limited in distribution and abundance, supported diverse and abundant groups of fishes, particularly those species of economic value to nearshore fisheries. This relatively shallow rock habitat also harbored high numbers of YOY rockfishes and served as a nursery for these fishes. To increase protection of these nearshore species associated with limited amounts of rock habitat, the boundaries of BCER should be extended both north and south.

To afford some protection to all benthic fish assemblages within our study site, the boundaries of BCER also would have to be extended offshore to encompass the highly diverse deep-water canyon assemblages associated with rock crevices and overhangs as well as those species most abundant over soft fine sediment on the canyon walls. From results of our past research in Monterey Bay, rock outcrops on relatively steep canyon walls can offer natural refuge to some economically valuable species in deep water (Yoklavich et al. 2000). These deep-water assemblages include several species whose populations are in severe decline (i.e., bocaccio, cowcod, and canary rockfish). Based on the species-habitat work completed as part of this project, and other published studies, it is clear that species composition of the BCER will be greatly enhanced and protected by extending the boundaries a short distance into deep water. Presently there are no marine reserves in California, if not on the entire West Coast, that afford protection to those habitats and associated fauna at water depths greater than 100 m.

Our comparisons of fish density and size inside and outside BCER did not indicate significant differences. Various explanations can be considered, including:

1) *Inadequate recovery time or time of closure to reflect significant effects.* There is evidence elsewhere on the West Coast that some rockfish species and lingcod protected within a few existing no-take marine reserves have greater abundance and/or size, and consequently increased spawning biomass and reproductive potential, compared to those in adjacent fished areas. For example, reproductive potential of copper rockfishes inside a 27-year-old marine reserve in shallow water of Puget Sound, Washington, was 55 times greater than that of coppers subject to heavy fishing pressure outside the reserve (Palsson 1998). This enhanced reproductive potential derived from greater densities and larger sizes of coppers inside the reserve. Similarly, significantly more and larger lingcod and copper rockfishes were observed inside a tiny 6-year-old no-take reserve in the San Juan Islands, Washington, compared to adjacent unprotected areas (Palsson and Pacunski 1995).

Reproductive potential for black-and-yellow and kelp rockfishes inside two small longtime reserves in Monterey Bay, California (i.e., Point Lobos State and Ecological Reserve [closed to fishing for more than 20 years prior to study], and Hopkins Marine Life Refuge [closed to fishing for 12 years prior to study]) was significantly greater than reproductive potential for these species in heavily fished areas immediately outside the reserves (Paddack and Estes 2000). These researchers found no significant differences in reproductive potential of these species in shallow water (14 m) inside and outside of the BCER, which was closed to fishing in 1994, just 1–2 years prior to their surveys.

This suggests that the 3.5 years of protection prior to our surveys in deep water of BCER in 1997 and 1998 may not have been long enough to reflect differences in density, size and subsequent reproductive potential. Length of time of protection is especially critical when evaluating effects of reserve protection on rockfishes. Many rockfish species, particularly those in deep water, have maximum longevity of 50 years and greater. As a group they are slow growing and have low natural mortality. Recruitment of young fishes varies greatly from year to year. Because of these life history characteristics, the benefits or positive effects of areas protected from harvest could take years to accrue. Because BCER was closed to fishing for a relatively short period (i.e., 3.5 years) before initiation of our study, our inventory of habitats and associated fishes can be considered a valuable baseline from which to evaluate future changes to BCER populations of benthic fishes in deep water and the expectations of BCER to maintain species and habitat diversity.

2) *Low harvest rates.* While we do not have estimates of fishing rates along the Big Sur coast, especially relative to BCER, this remote coast with limited access likely receives relatively less fishing pressure than similar types of habitat closer to fishing ports. The expected positive effects of marine protected areas, for example, increased abundance and sizes inside the protected area compared to adjacent unprotected areas, in large part depend on the contrast in fishing pressure between the two areas. This contrast might not have been great in deep waters of the study sites. It is especially important to continue to monitor this reserve and adjacent areas if fishing pressure is expected to increase along this coast.

3) *Reserve too small.* The size of BCER, about 8 km^2 in area and 4.5 km in length along the coast, may not encompass the home range and movements of some benthic fish species and therefore may not adequately protect these fishes. We did not assess the movements of fishes within BCER, but many of the nearshore rockfish species are thought to be relatively sedentary (Stanley et al. 1994; Lea et al. 1999). Extent of movement depends on season for some species, temperature, food supplies, and developmental stage (with young fishes generally more mobile than older stages). A recent tracking study of electronically tagged greenspotted rockfish and bocaccio in deep water of Monterey submarine canyon documented considerable short-term variation in movement (Starr et al. 2002). Even infrequent movements of fishes outside the boundaries of BCER could invalidate the protection of the reserve, and impede detection of reserve effect.

4) *Lack of enforcement*. Illegal fishing occurs within the boundaries of BCER (Paddack and Estes 2000), as it likely does in all areas where fishing is prohibited (see Proulx 1998 for discussion on enforcement issues and marine reserves). While we have no good estimates of the extent of poaching in the BCER, this activity could have influenced our results in assessing the effects of the reserve on density and size of fishes.

Our Recommendations

1) Develop a routine monitoring program to estimate changes in species composition, abundance, and size over time of increased protection in the BCER. Develop standard transects in the BCER to estimate habitat changes through time. The interval of time between surveys should reflect expected effects relevant to the life history characteristics of protected species. With an established long-term monitoring protocol, BCER could serve as a valuable reference site or control for monitoring local trends in populations and ecosystem processes.
2) Address seasonal variability in abundance and habitat use by conducting surveys at different times of year. Suitability and use of habitat may change seasonally for different species, particularly considering age and reproductive condition.
3) Extend the boundaries of the BCER northward to include rocky outcrop and isolated pinnacles adjacent to BCER. From our surveys, this complex rock habitat supports relatively high densities of several species of fishes. Protection of these benthic fishes would be increased if this area was included within BCER. This boundary should be placed at a more easily recognized point than is now the case, and perhaps can be made contiguous with the Landels-Hill Terrestrial Reserve.
4) Extend the boundaries of BCER westward to include the 500-m isobath. From our work, excellent rockfish habitat occurs in deep water just outside the BCER, specifically in the heads of submarine canyons.
5) Extend the boundary south to Gamboa Point in order to make this boundary clearly recognized from sea. Coupling this southern extension with the suggested offshore extension (item 4 above) will result in increased protection of significant rock habitat and associated species in the head of an offshore submarine canyon.
6) Increase the size of BCER by extending the boundaries as recommended above. Increased size of the reserve will reduce the percentage of time that fishes move outside the boundaries, becoming vulnerable to fishing.
7) Create ecological reserves in other areas of the California coast to serve as replicates for the BCER. Monitoring replicate reserves and adjacent unprotected areas will strengthen our evaluation of reserve effects. These replicate reserves should be located in different bioregions in order to evaluate sufficiently those reserve effects related to representative habitats and faunal assemblages. These reserves would be located and integrated with potential natural refugia and existing protected areas.

Contributions

Our research directly addresses the first four research topics initially identified by CDFG for BCER: (1) habitat surveys, (2) inventory of deep-water fish assemblages, (3) estimates of population, and (4) size structure of sport and commercial fish species using in situ methods. Additionally, footage from our underwater video surveys will be available for other investigators to determine densities, distribution, and habitat specificity for dominant species of macroinvertebrates and algae; this also is a research priority listed by CDFG.

Methodologies and results from this project will be instrumental in the implementation of recent fishery management and marine reserve legislation in California (i.e., Marine Life Management Act and Marine Life Protection Act [MLPA]). Assessing habitat availability and species-specific habitat associations are paramount to locating marine protected areas and to evaluating their effectiveness. Results of our work should improve the conceptual design of marine protected areas and assist in developing an effective network of marine protected areas for California (as called for in the MLPA). These results also will serve as baseline data in initial assessments of many nearshore fish species and development of fisheries management plans, as called for in California's Marine Life Management Act.

This study also addresses research priorities identified by NMFS and the Pacific Fishery Management Council, such as identification, characterization, and description of essential elements of habitat for commercially managed fish species, particularly in water depths greater than 20 m; the use of reserves as a supplement to fisheries management; improving stock assessments by including habitat-specific estimates of species abundance. Our results also will be valuable to the long-term site characterization and monitoring priorities identified by the Monterey Bay National Marine Sanctuary, as implemented by the newly funded Sanctuary Integrated Monitoring Network (SIMoN) Program.

A major rationale of our study has been to provide information on the relationship between fish and particular habitats so managers will be able to ensure the wise management of valuable resources. Our results are complementary to the long-term research program conducted by CDFG on shallow-water fishery resources in BCER. Our study also provides fishery-independent estimates of population parameters (sizes, species composition, habitat-specific densities) that are critical to the interpretation of local fisheries data (e.g., artisanal hook-and-line fishery off Big Creek and CDFG onboard monitoring of the Commercial Passenger Fishing Vessel fishery from 1987 to 2000).

Figures

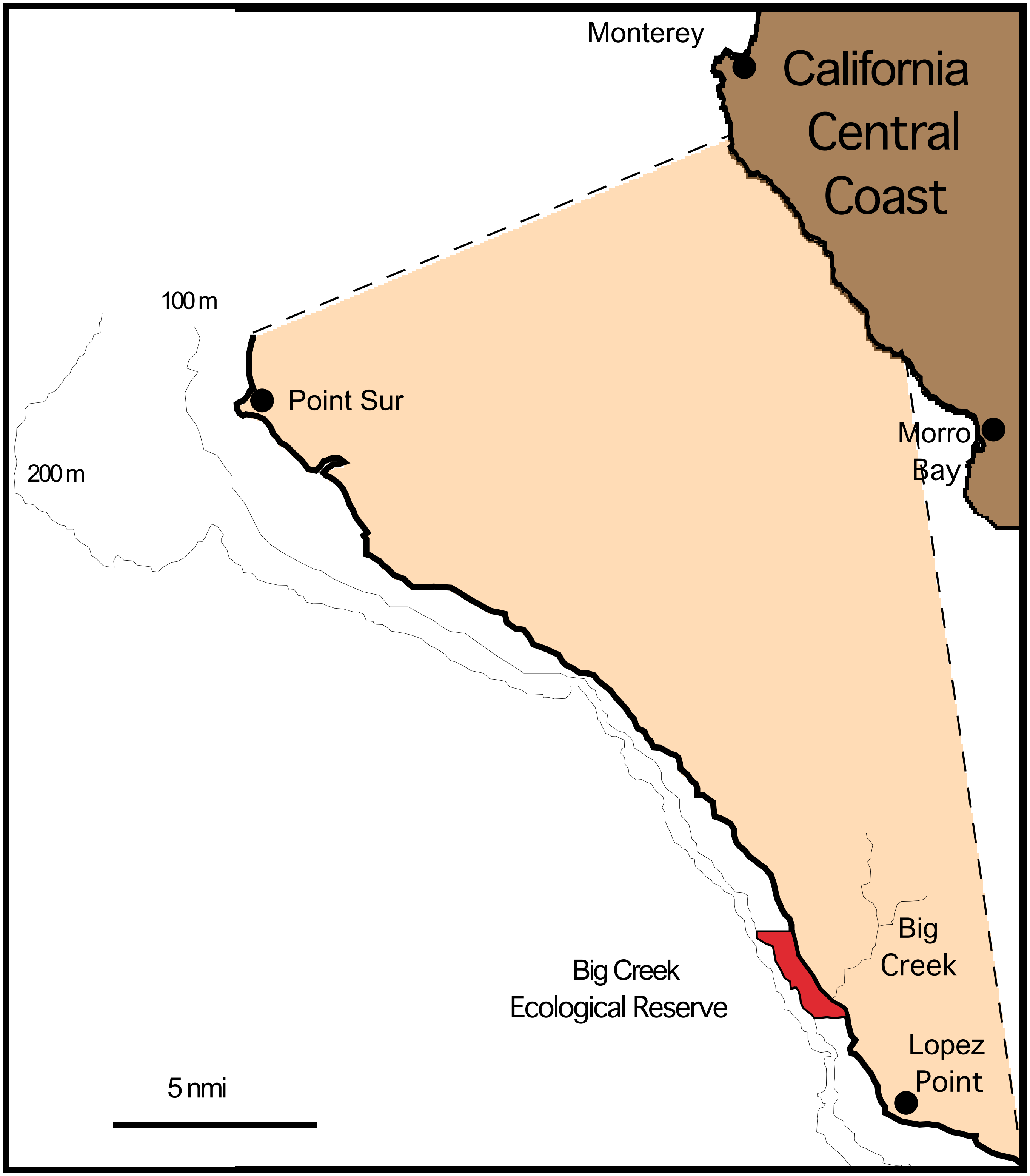

FIGURE 1. Big Creek Ecological Reserve study site off Central California coast (modified from original by C. Pomeroy, UC Santa Cruz).

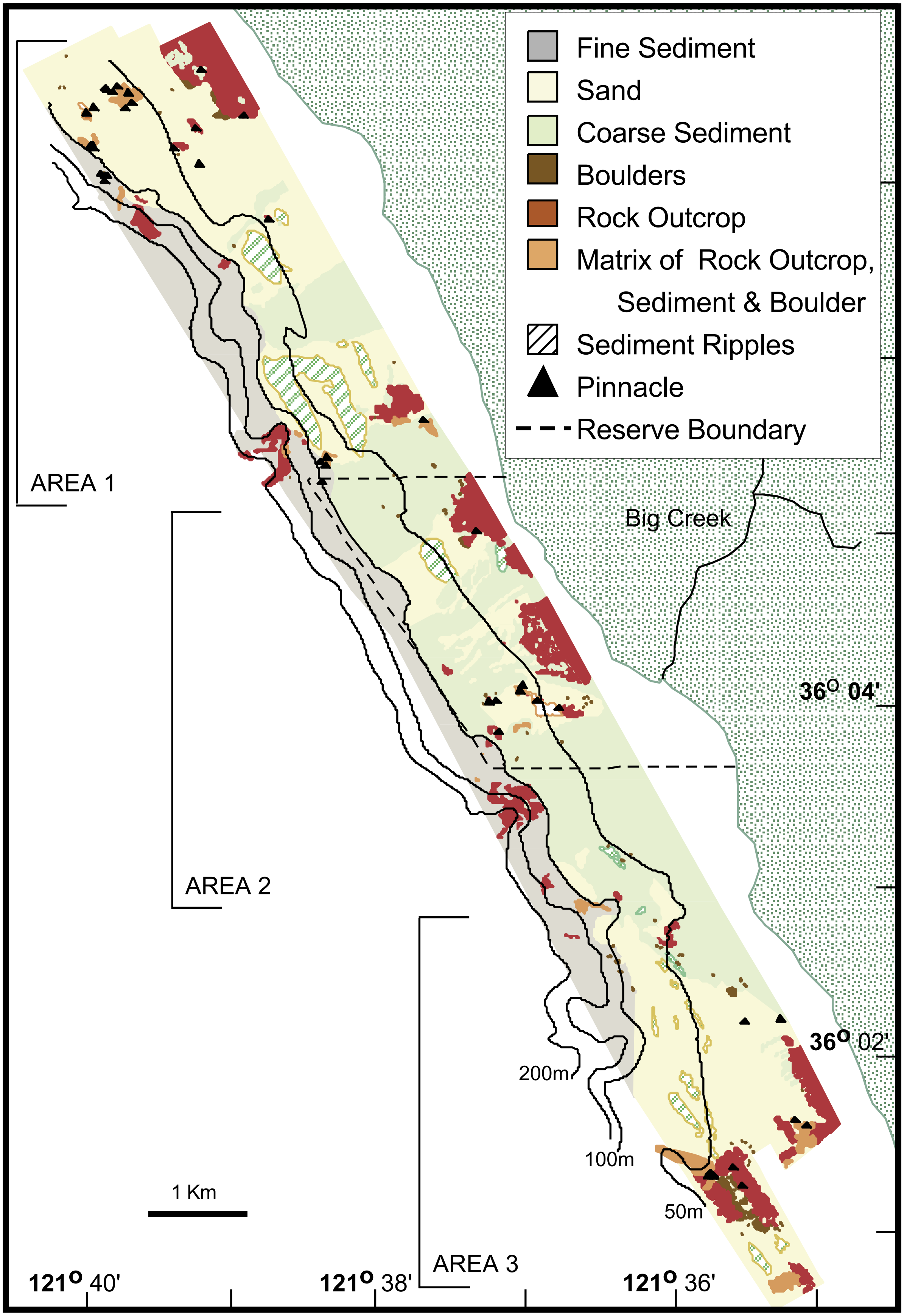

FIGURE 2a. Seafloor substrata types in our study area in and around the Big Creek Ecological Reserve, as identified from sidescan sonar and observations from submersible. Areas 1–3 are enlarged in Figure 2b–d.

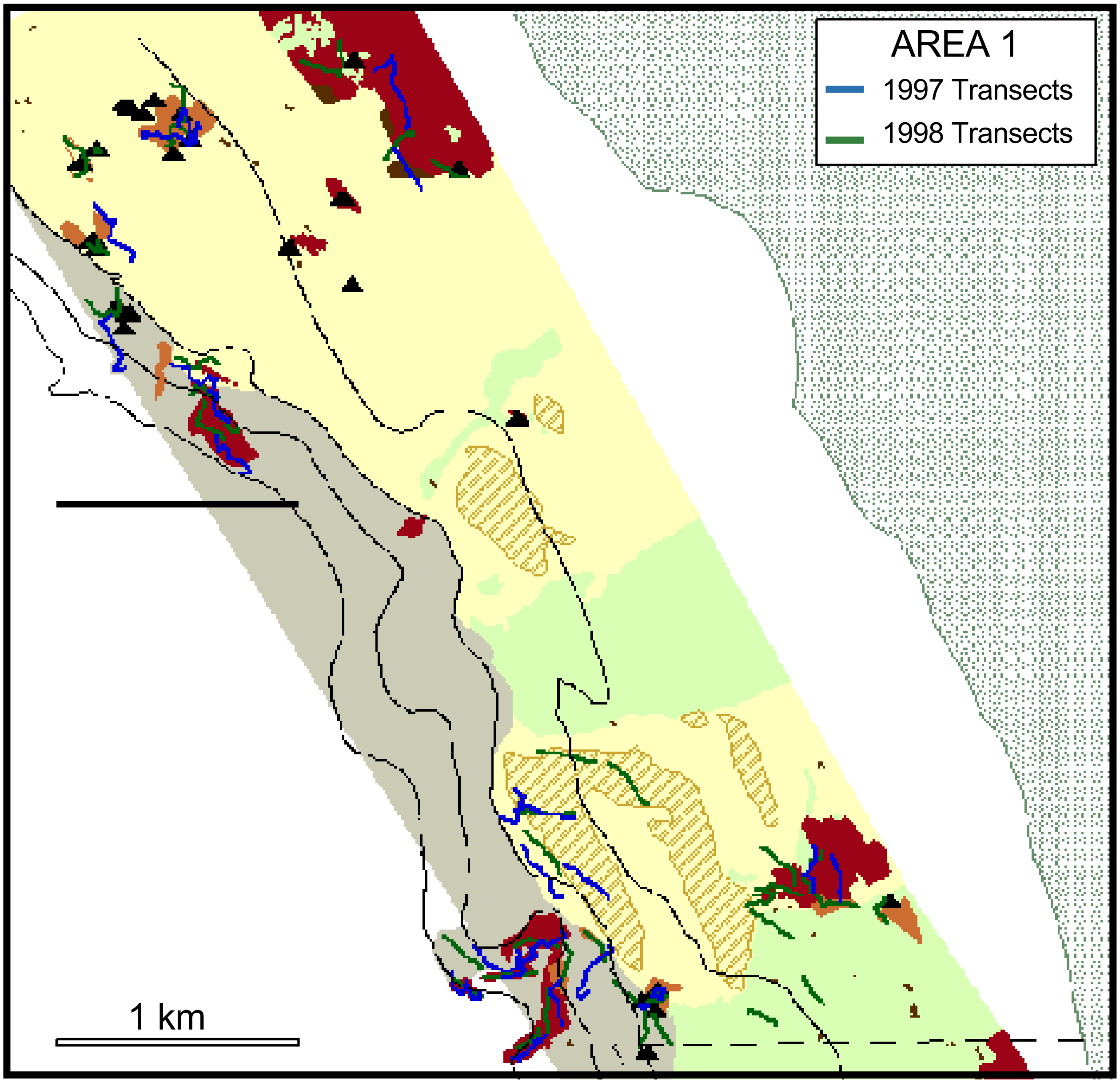

FIGURE 2b. Seafloor substrata types and video/submersible transect survey lines in our study Area 1, to the north of Big Creek Ecological Reserve.

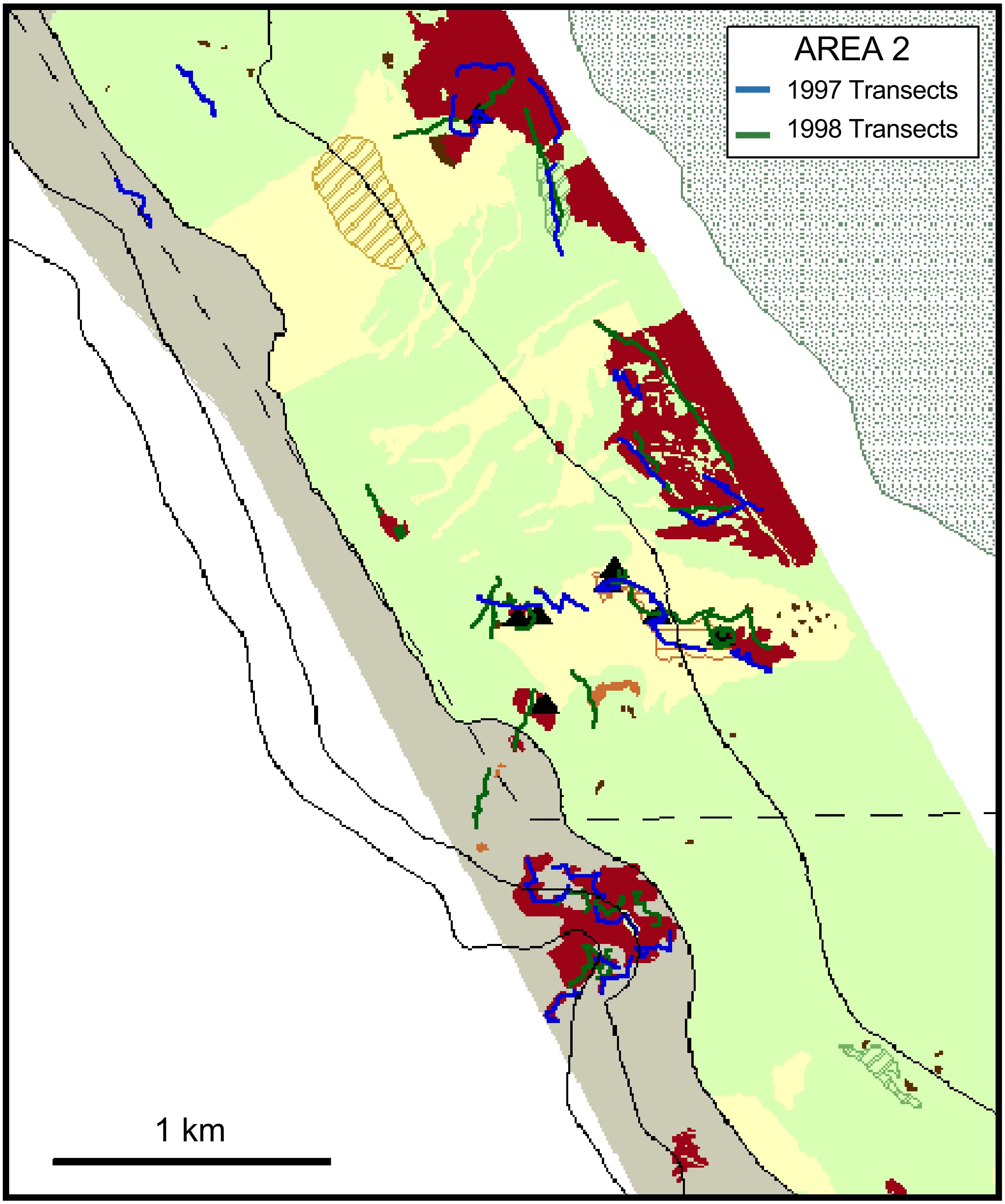

FIGURE 2c. Seafloor substrata types and video/submersible transect survey lines at our study sites in Area 2, within Big Creek Ecological Reserve and to the south.

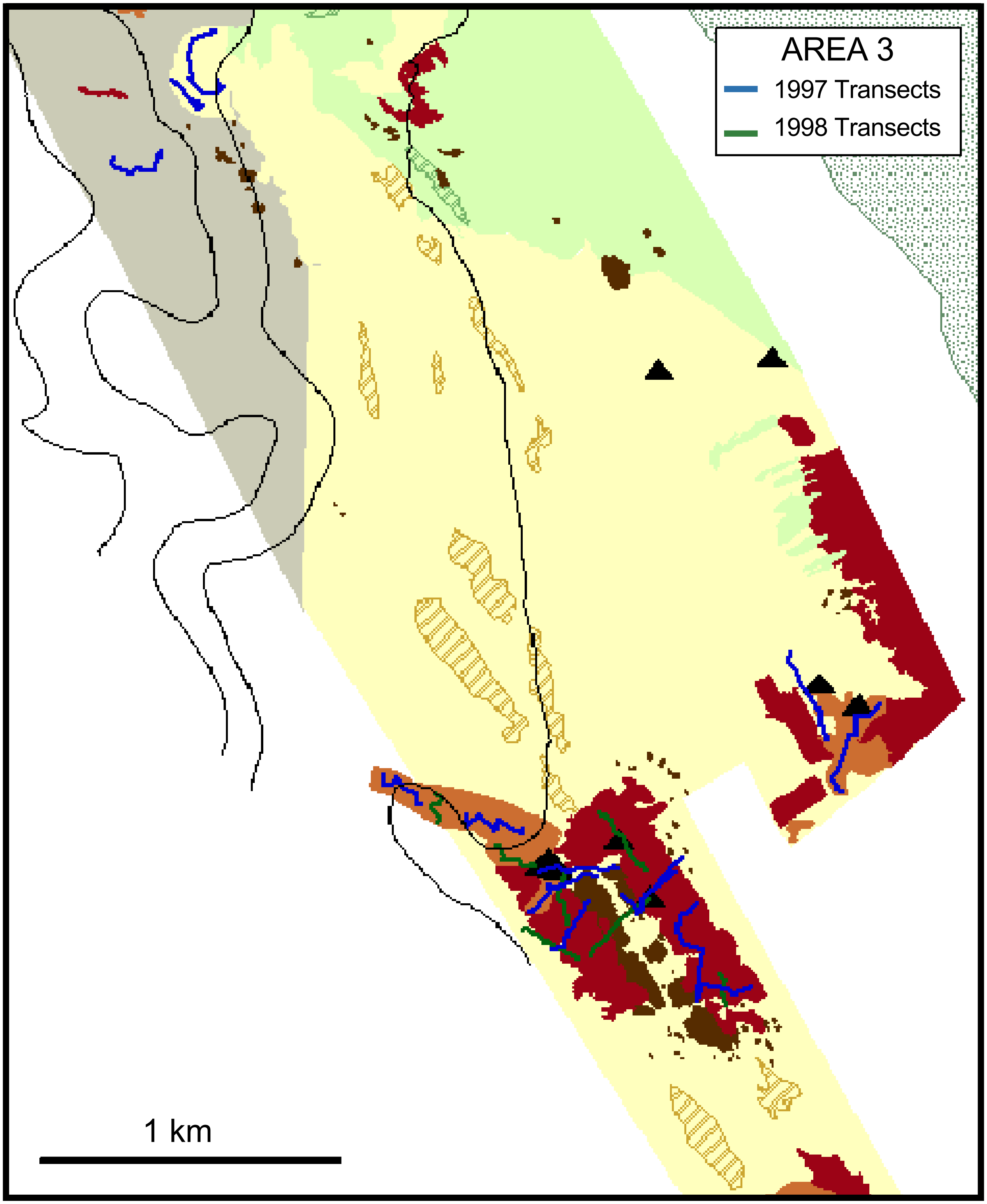

FIGURE 2d. Seafloor substrata types and video/submersible transect survey lines at our study sites in Area 3 to the south of Big Creek Ecological Reserve.

FIGURE 3. *Delta* submersible being launched in the Big Creek Ecological Reserve. Parallel lasers (arrows) mounted on either side of high-8 video camera and placed on starboard side of *Delta* submersible.

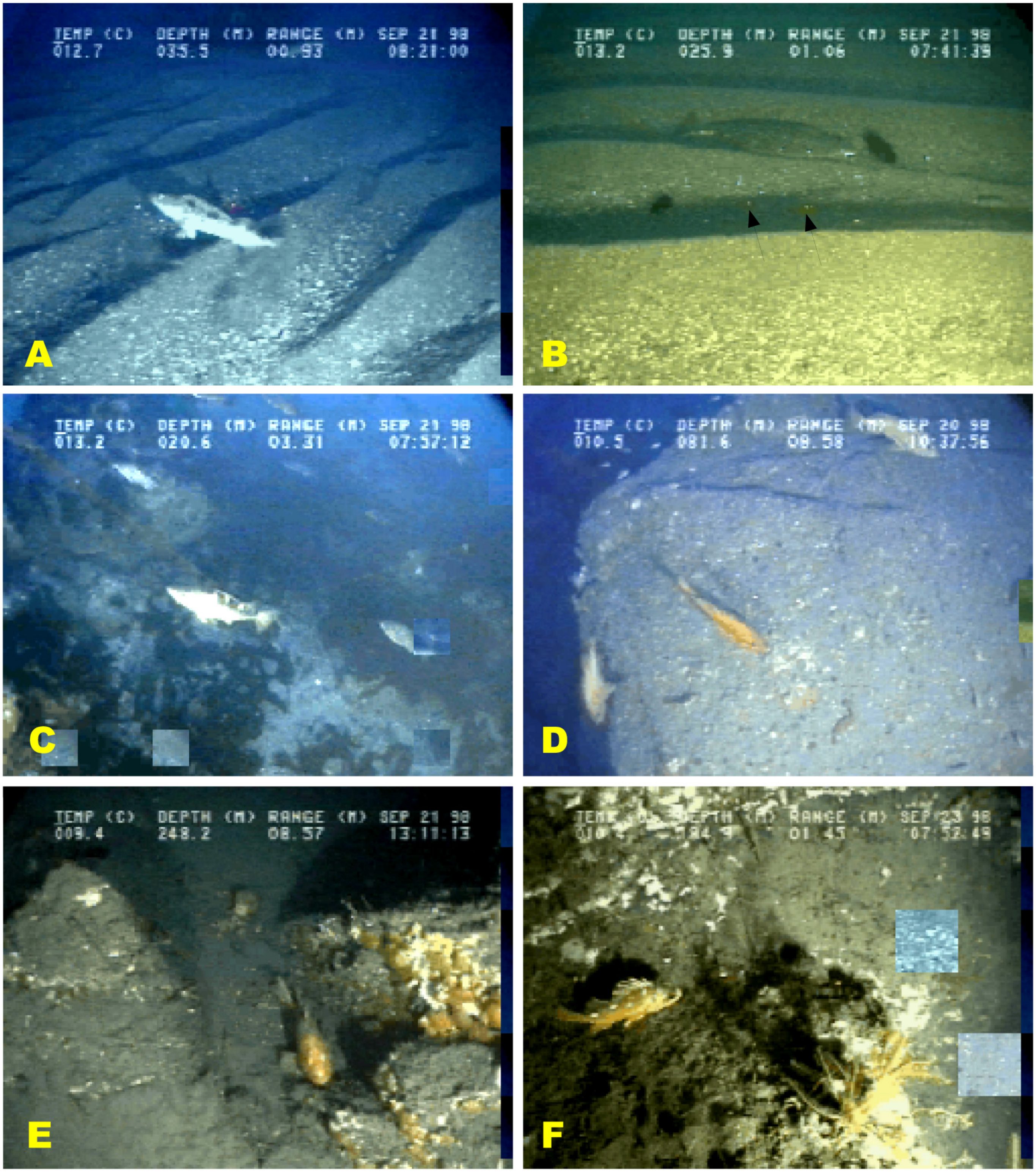

Figure 4: (a) Juvenile lingcod (*Ophiodon elongatus*) over sand waves at 36 m inside BCER; (b) California halibut (*Paralichthys californicus*) over sand waves at 26 m inside BCER. Arrows denote 20-cm interval laser beams; (c) Olive rockfish (*Sebastes serranoides*) and blue rockfish (*Sebastes mystinus*) over rock outcrop at 21 m inside BCER; (d) Vermilion rockfish (*Sebastes miniatus*) and pygmy rockfish (*Sebastes wilsoni*) on isolated rock pinnacle at 82 m just outside BCER; (e) Cowcod (*Sebastes levis*) near rock outcrop at 248 m in submarine canyon outside BCER; (f) Greenspotted rockfish (*Sebastes chlorostictus*) on rock canyon wall at 185 m outside BCER.

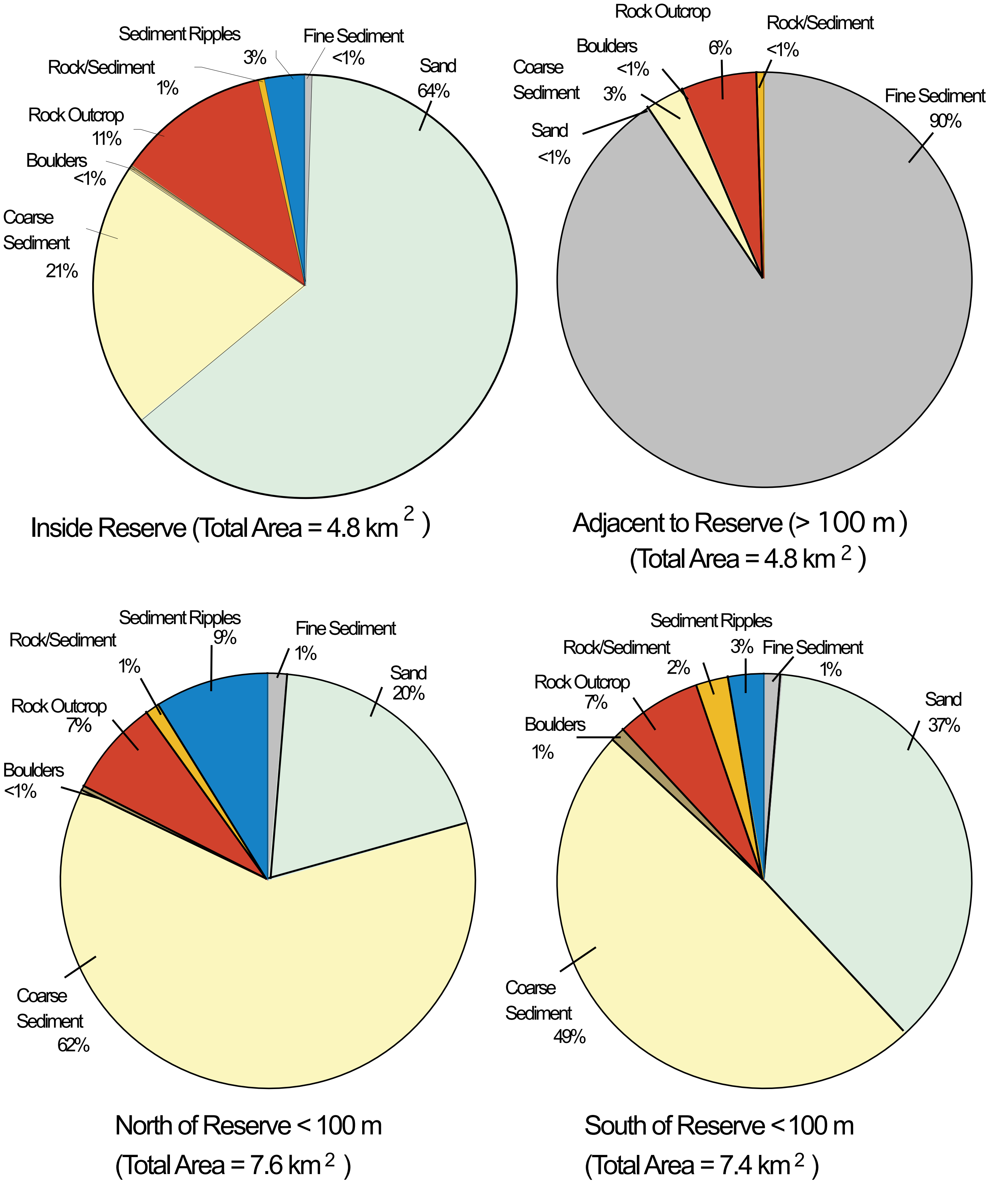

FIGURE 5. Seafloor substrata types inside and adjacent to the Big Creek Ecological Reserve study area.

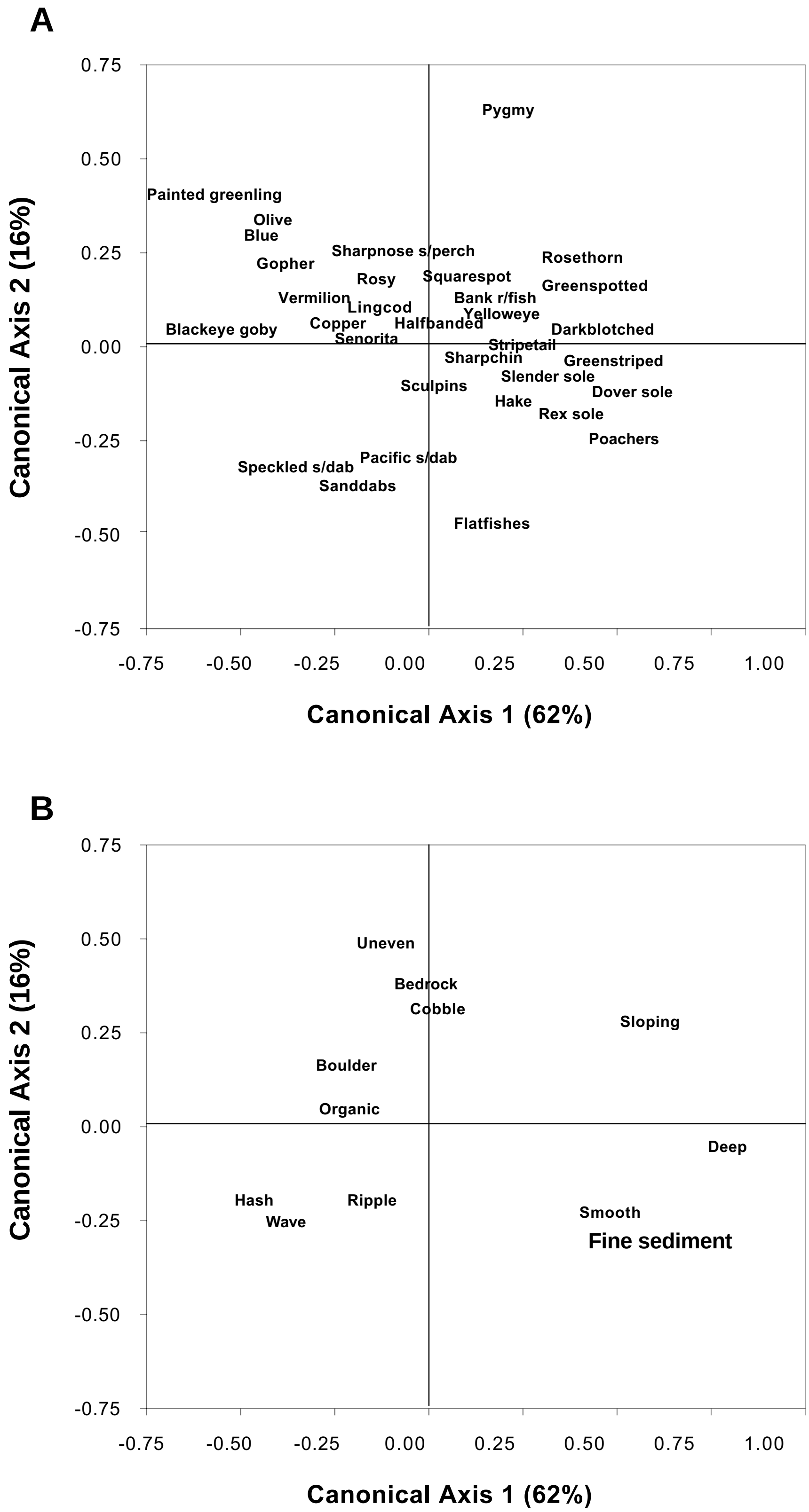

FIGURE 6. Results of canonical correlation analysis of fish-habitat data.

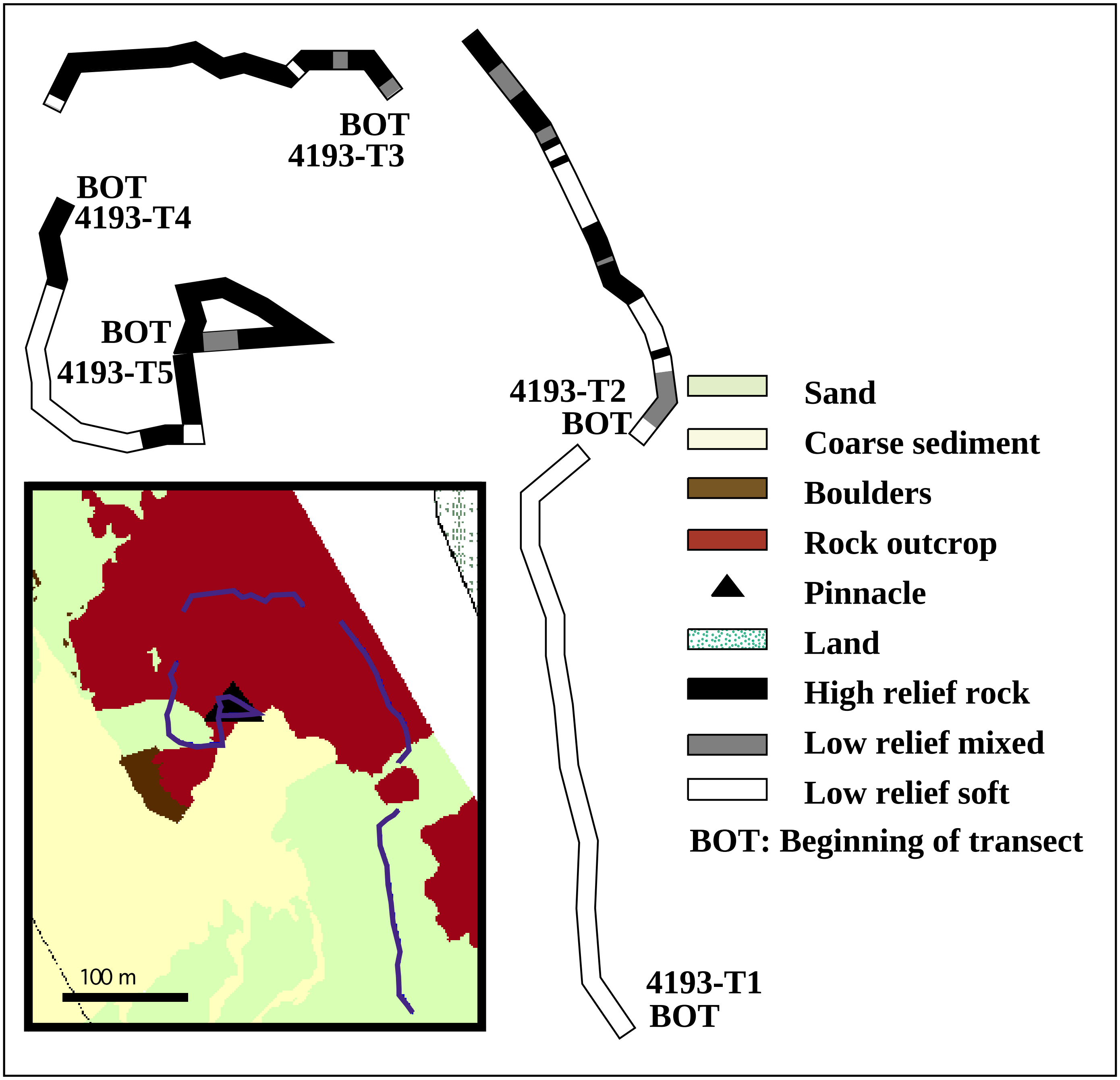

FIGURE 7. Examples of the distribution and relative size of various general habitat types along four transects (T1–4) during dive 4193 inside Big Creek Ecological Reserve.

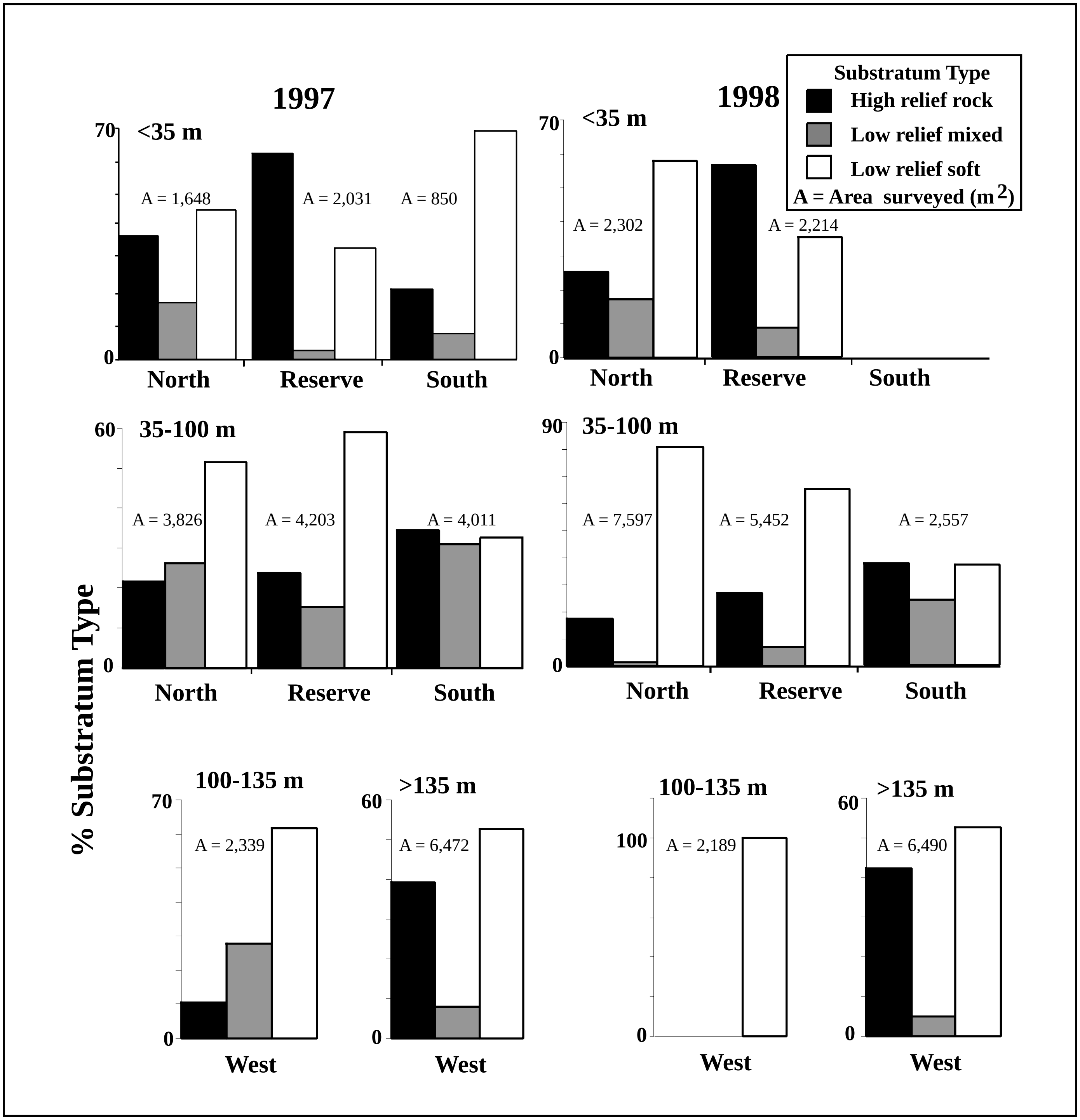

FIGURE 8. Percent of substratum types quantitatively surveyed inside, and to the north, south and west of Big Creek Ecological Reserve in four depth categories.

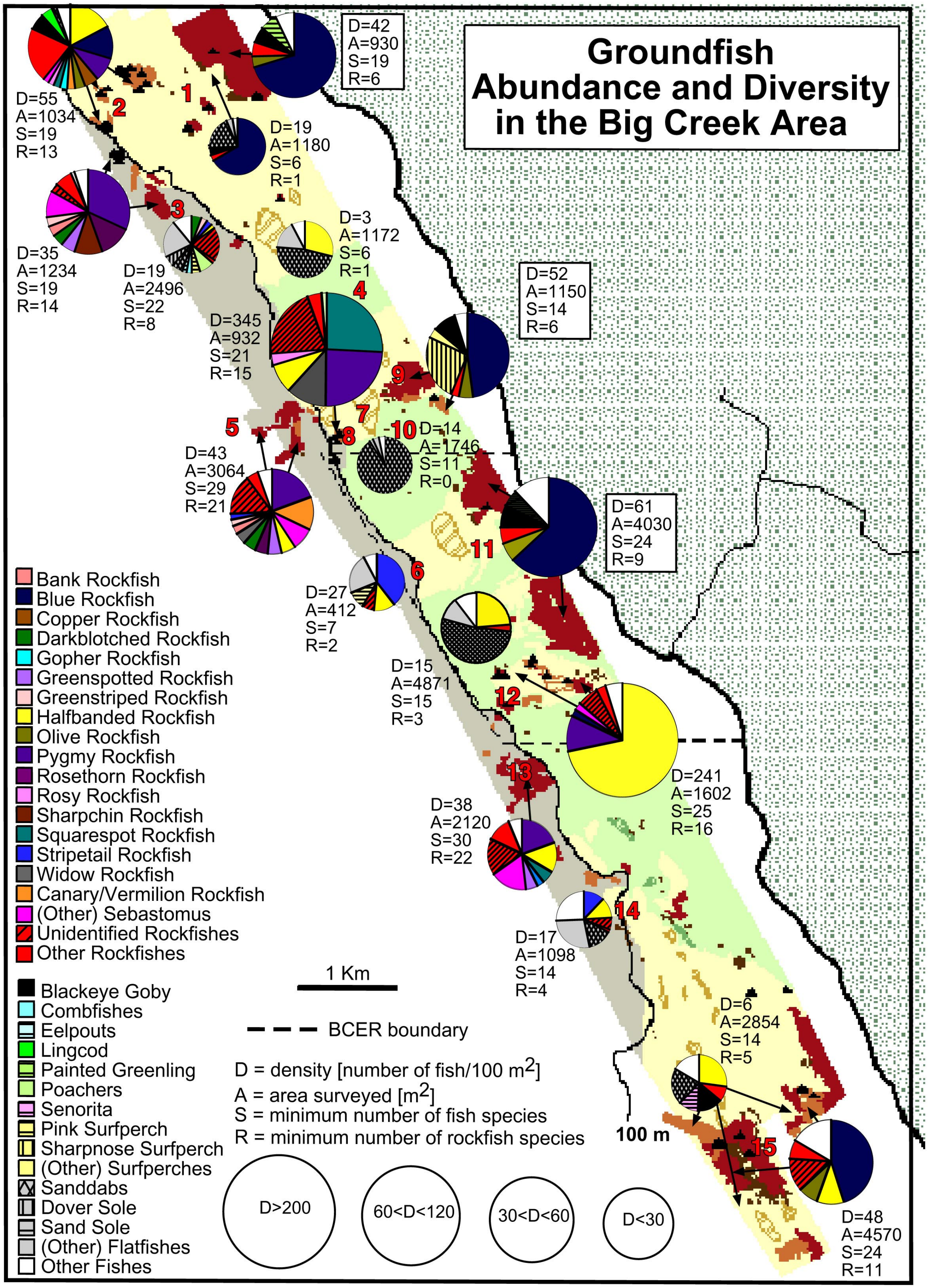

FIGURE 9a. Average density and diversity of benthic fishes at 15 sites in the Big Creek study area. Size of pie diagrams is scaled by density. (Enlargements of areas provided in figures 9b–d)

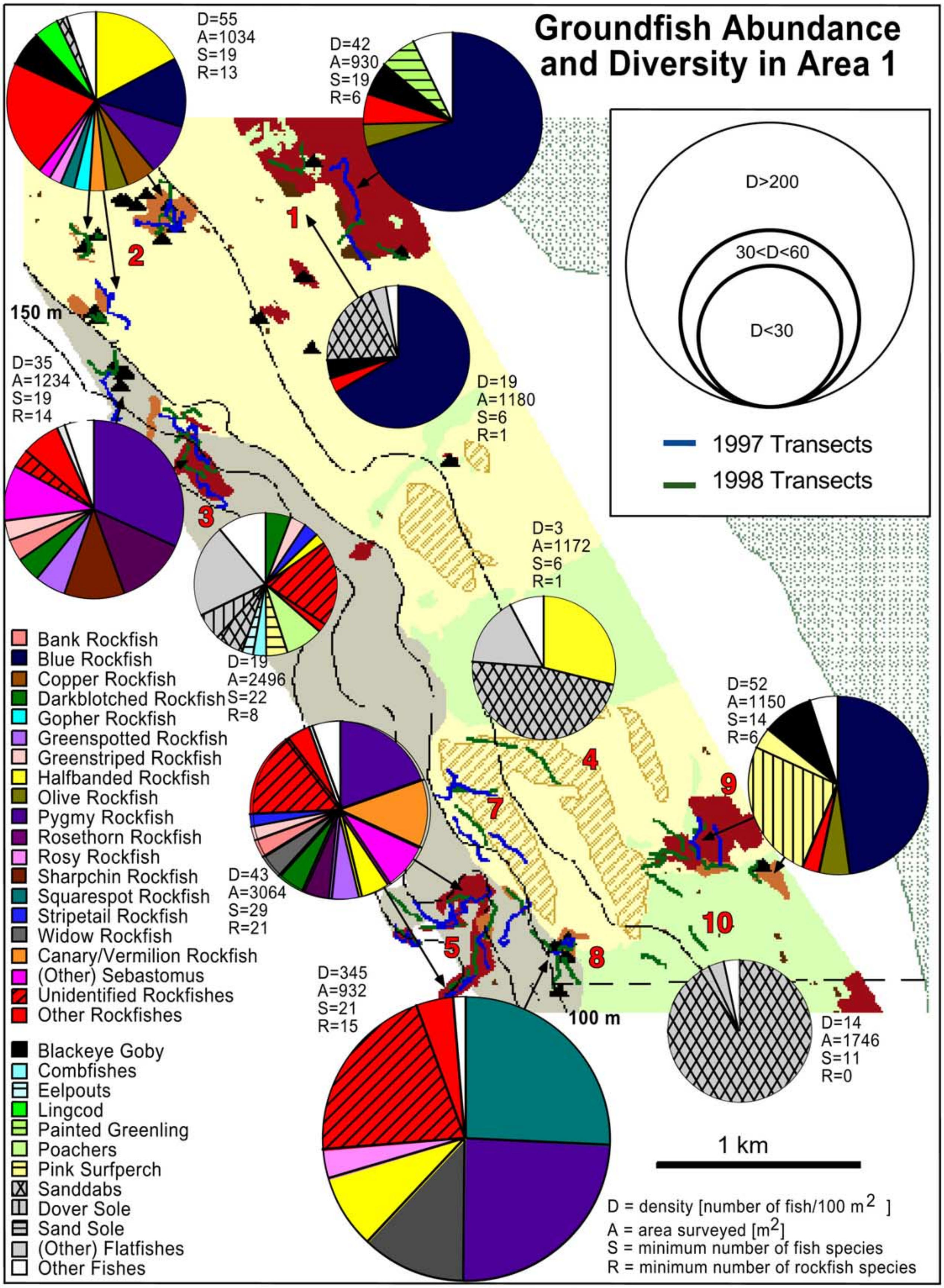

FIGURE 9b. Average density and diversity of benthic fishes at those sites to the north of Big Creek Ecological Reserve

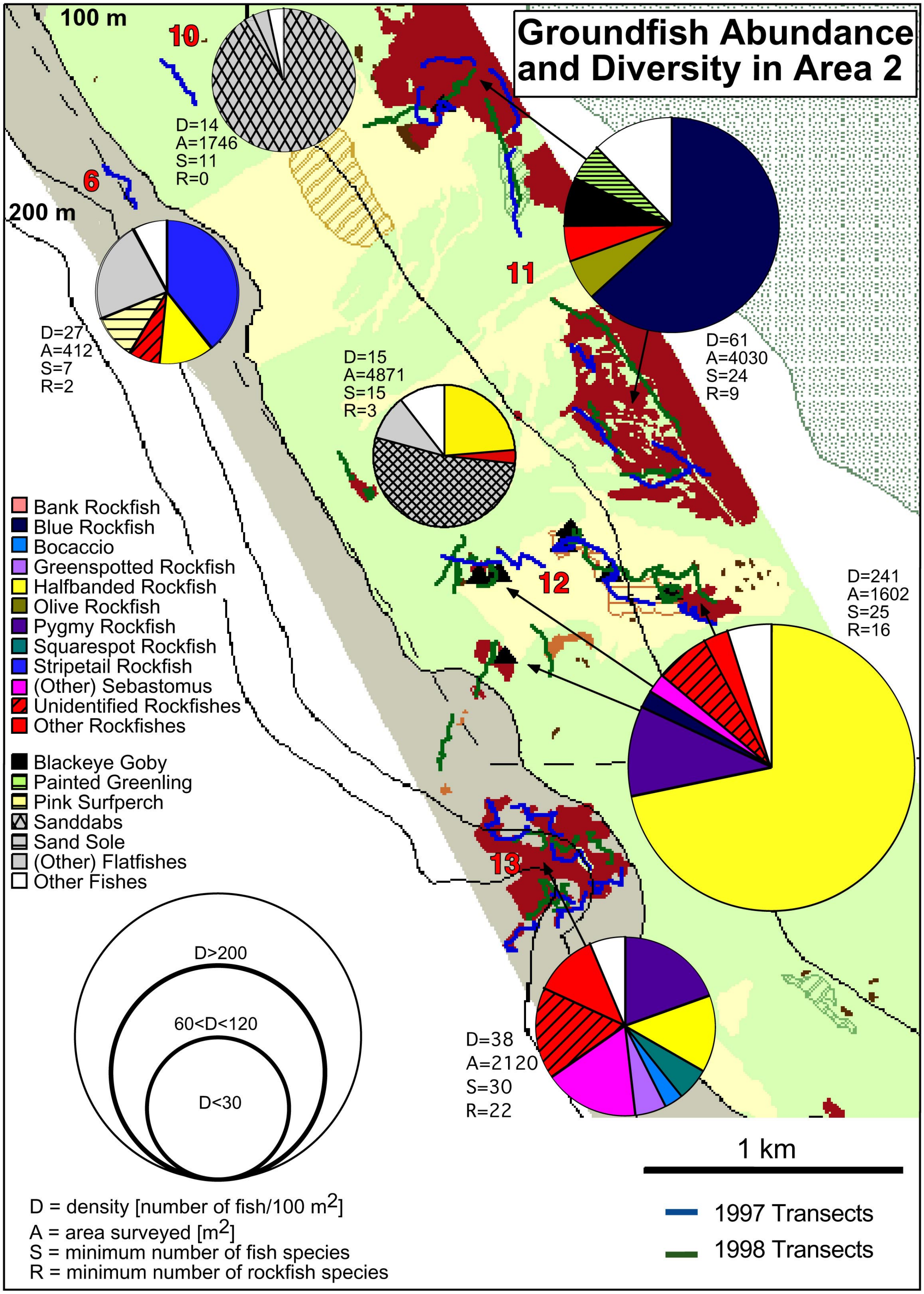

FIGURE 9c. Average density and diversity of benthic fishes at those sites inside and adjacent to the Big Creek Ecological Reserve.

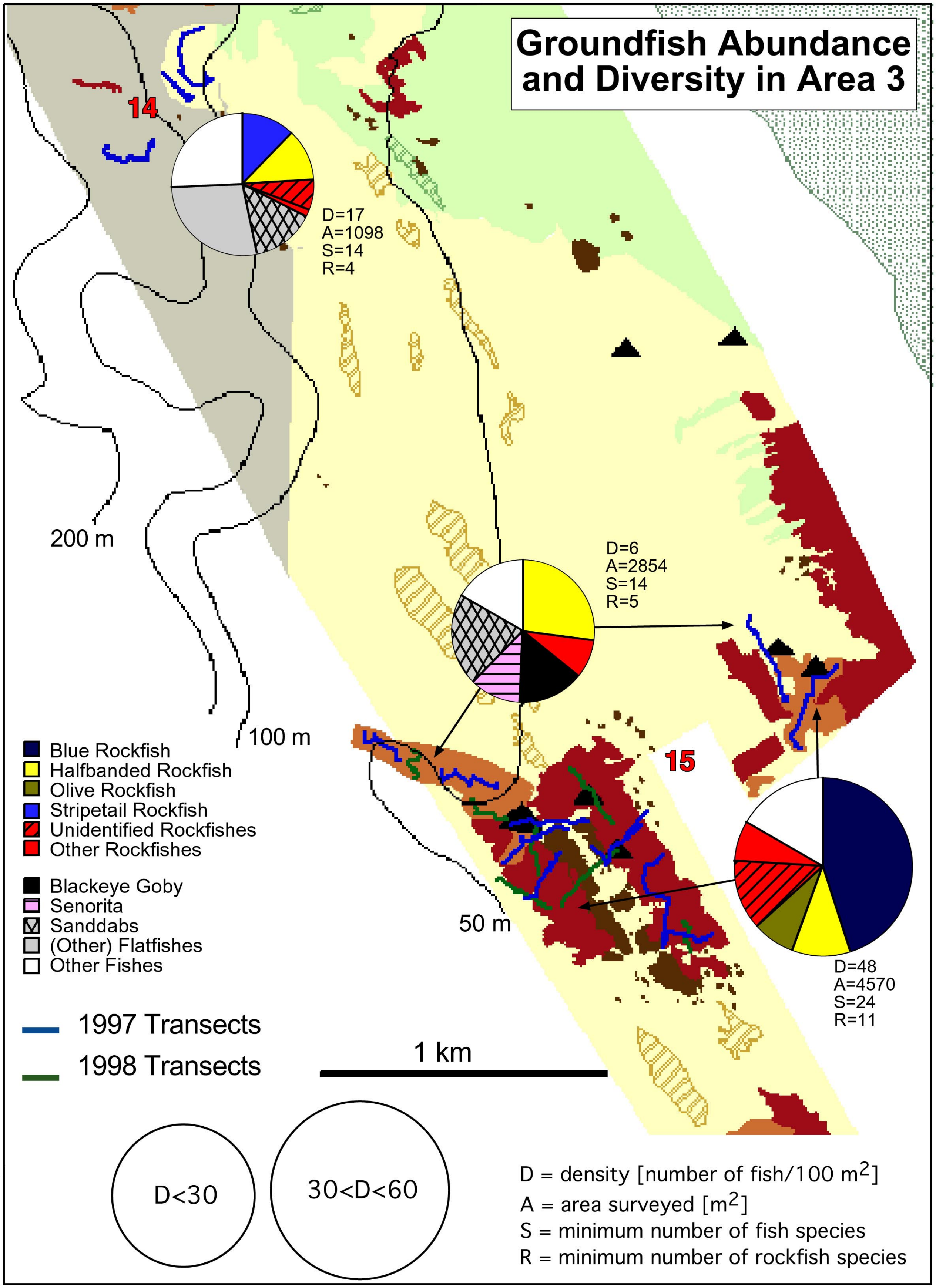

FIGURE 9d. Average density and diversity of benthic fishes at those sites south of the Big Creek Ecological Reserve.

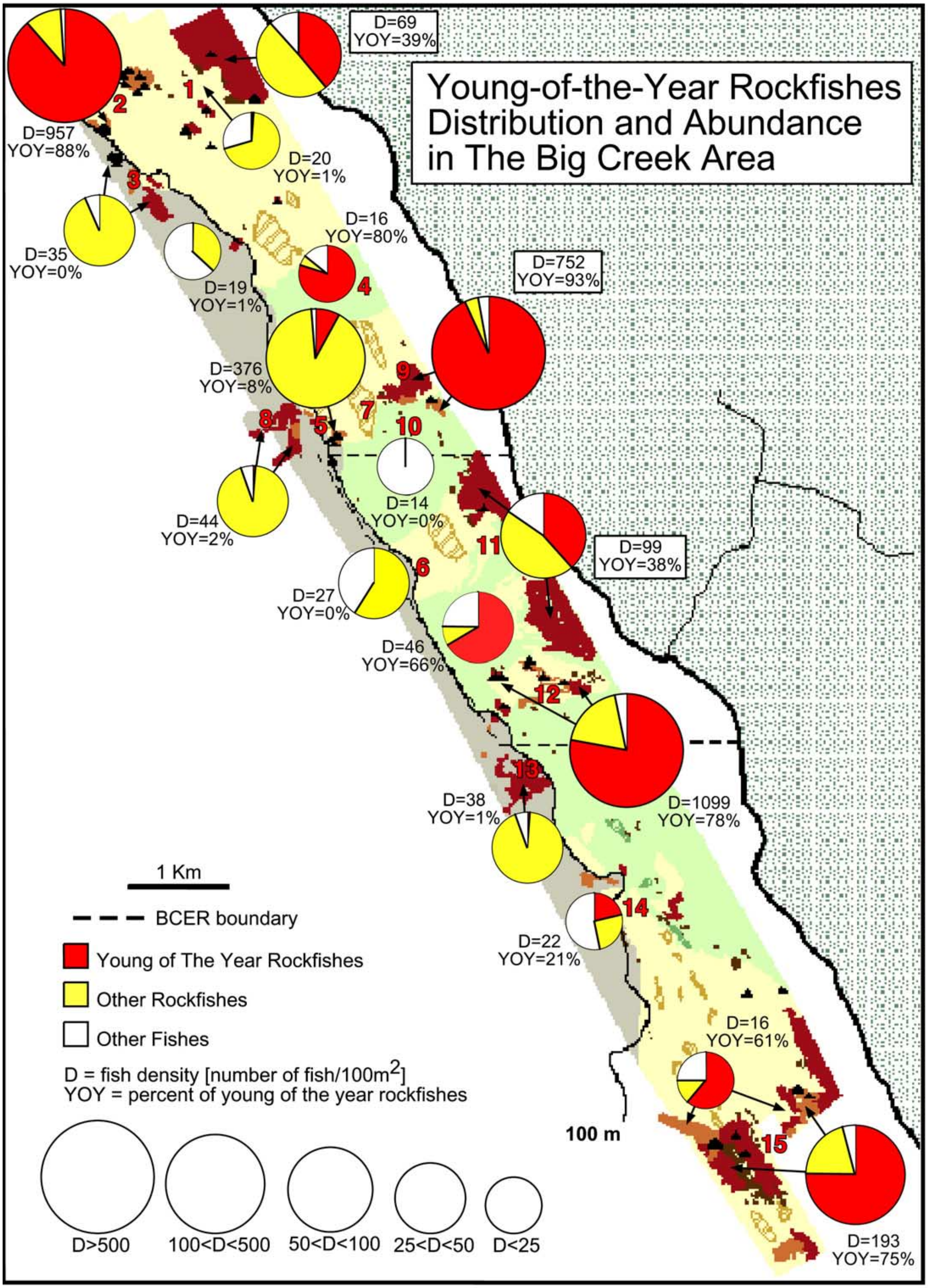

FIGURE 10. Distribution and average density of young-of-the-year (YOY) rockfishes (red), all adult rockfishes (yellow), and all other adult fishes (white) at 15 sites in the Big Creek study area. Pie diagrams are scaled by fish density (D).

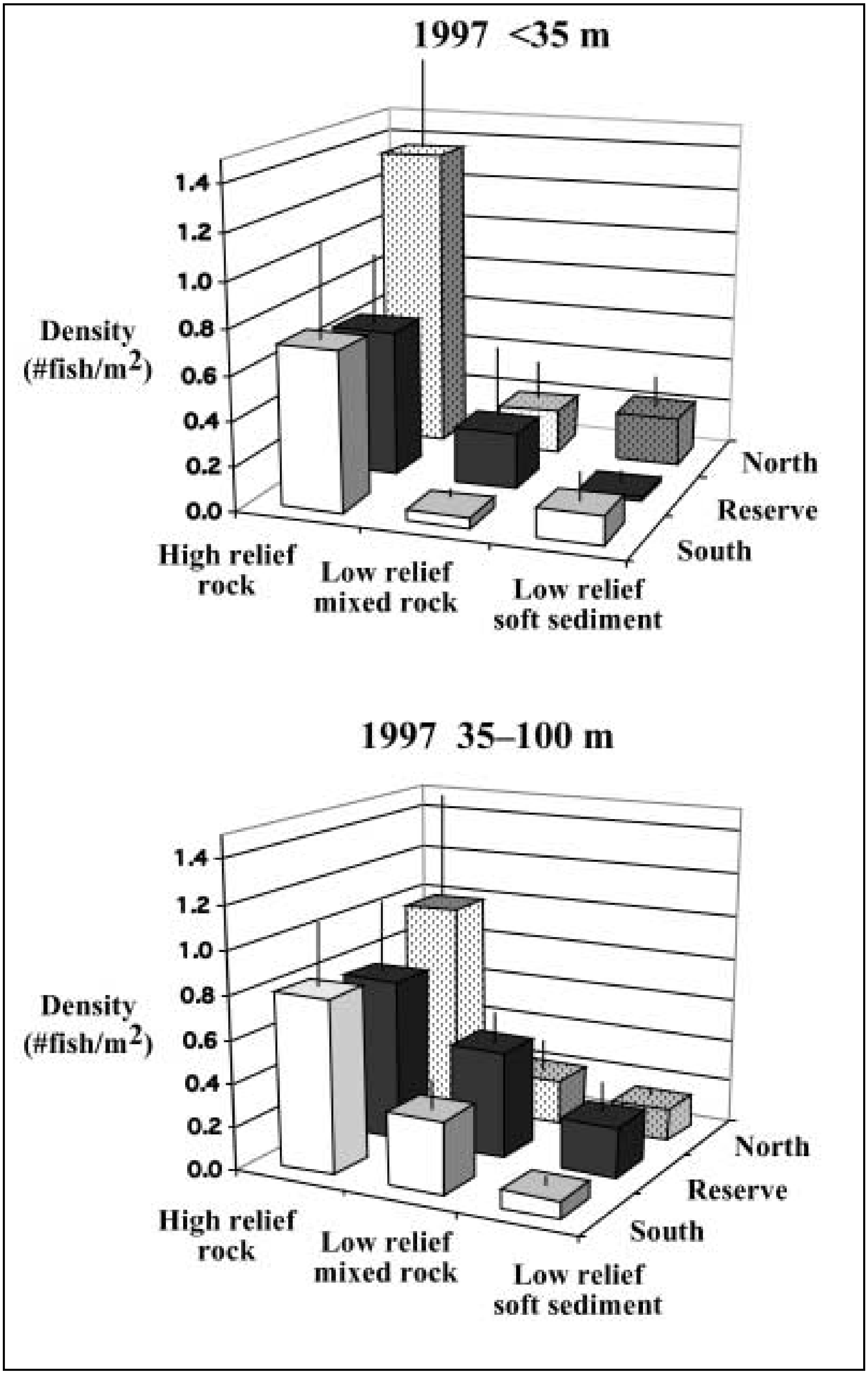

FIGURE 11. Mean density (#fish/m^2) of fishes at water depths <35 m and 35–100 m on three substrata (high relief rock, low relief mixed rock, low relief soft sediment), at three locations (north, south, and inside Big Creek Ecological Reserve) in 1997. Error bar is one standard error of the mean.

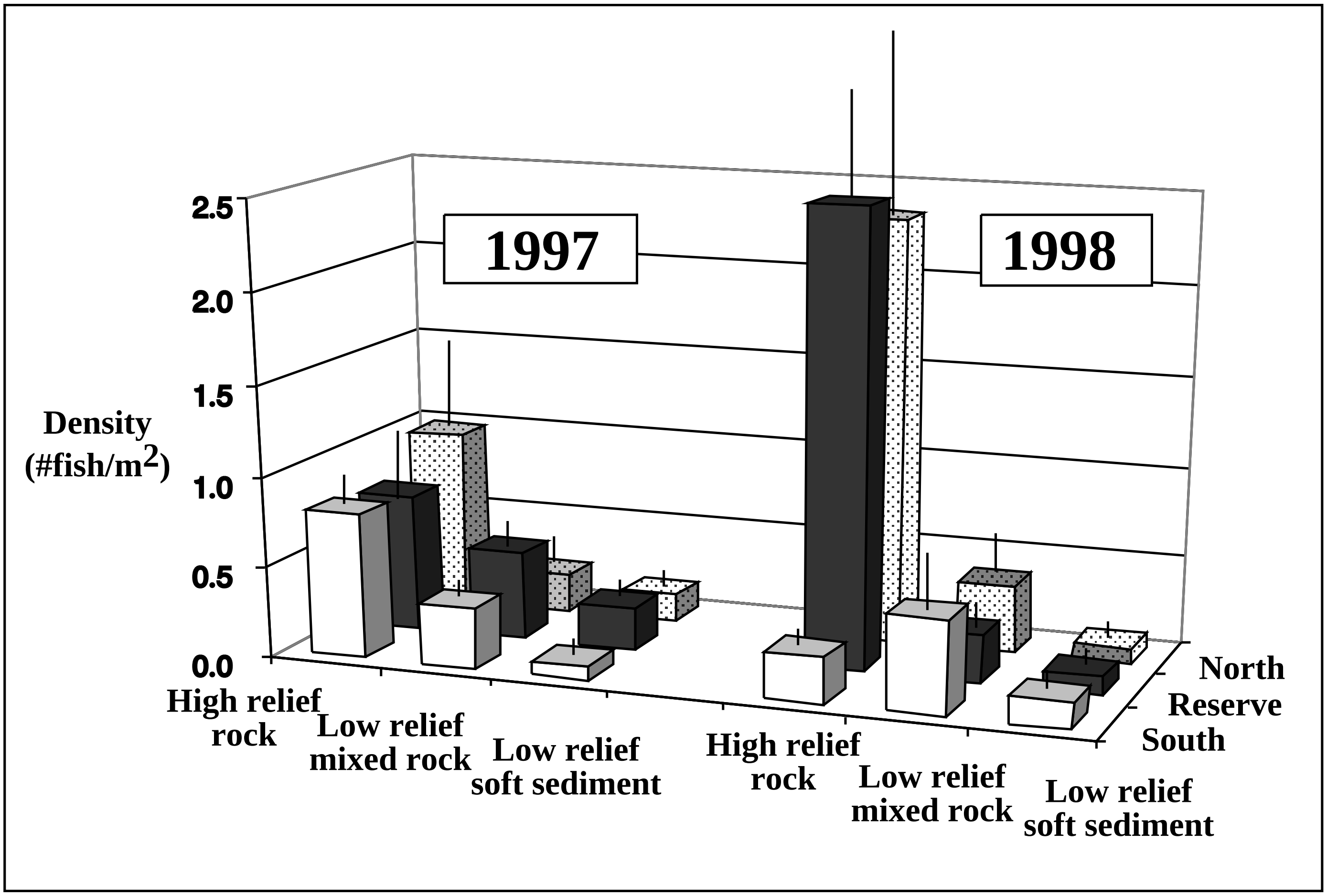

FIGURE 12. Mean density (#fish/m^2) of fishes at water depths 35–100 m on three substrata (high relief rock, low relief mixed rock, low relief soft sediment), at three locations (north,south, and inside Big Creek Ecological Reserve) in 1997 and 1998. Error bar is one standard error of the mean.

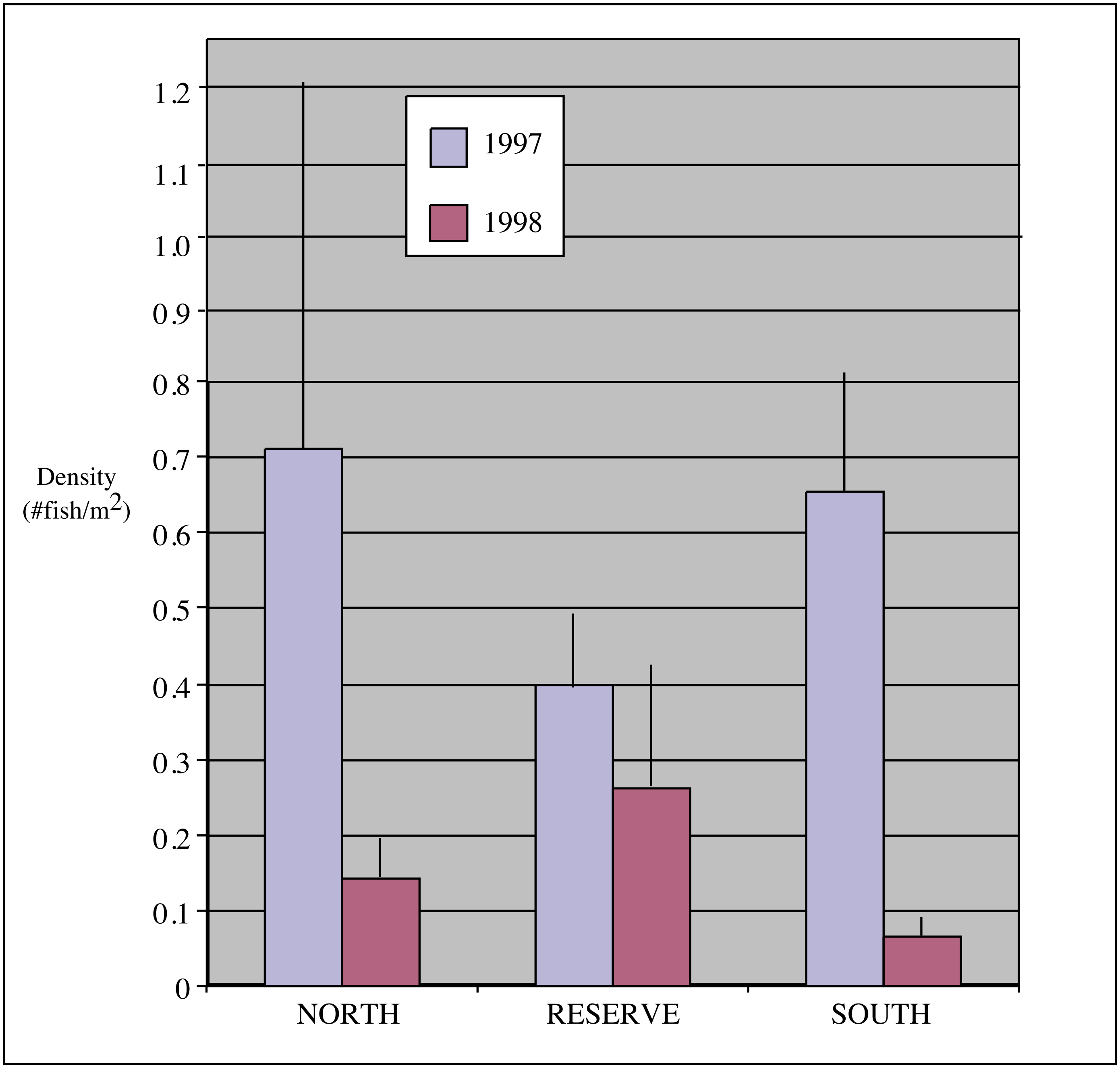

FIGURE 13. Mean density (#fish/m^2) of economically valuable species (i.e., blue, olive, vermilion, canary, gopher, copper, and yellowtail rockfishes, and lingcod) on high relief rock substratum among three locations (north, south, and inside Big Creek Ecological Reserve) in 1997 and 1998. Standard error bar is included.

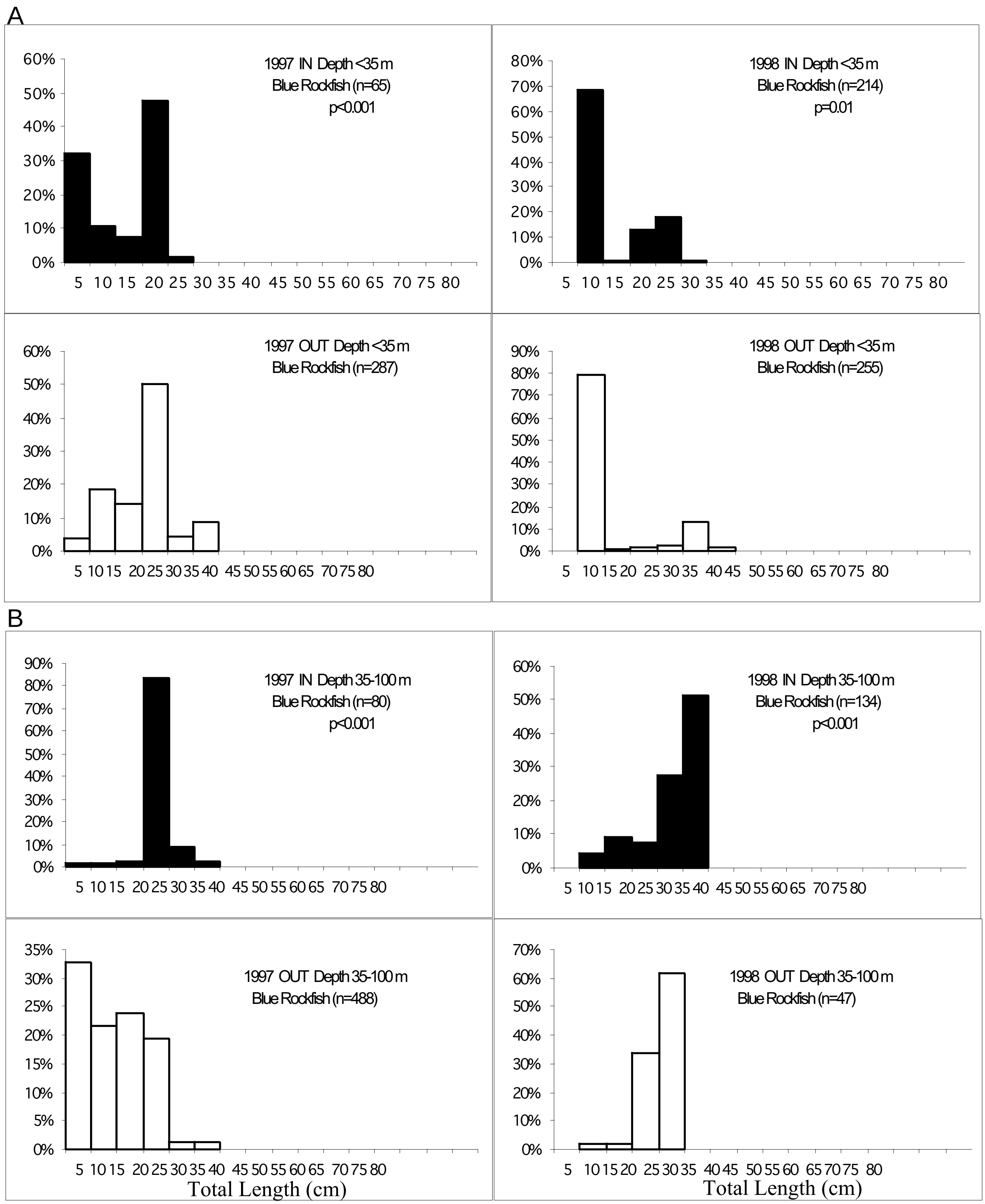

FIGURE 14. Percent frequency distributions of total length of blue rockfishes inside (IN) and outside (OUT) the Big Creek Ecological Reserve in 1997 and 1998 in water (A) <35 m depth and (B) 35–100 m depth. P values are from Kolmogorov-Smirnov goodness of fit comparisons between sizes in and out of reserve.

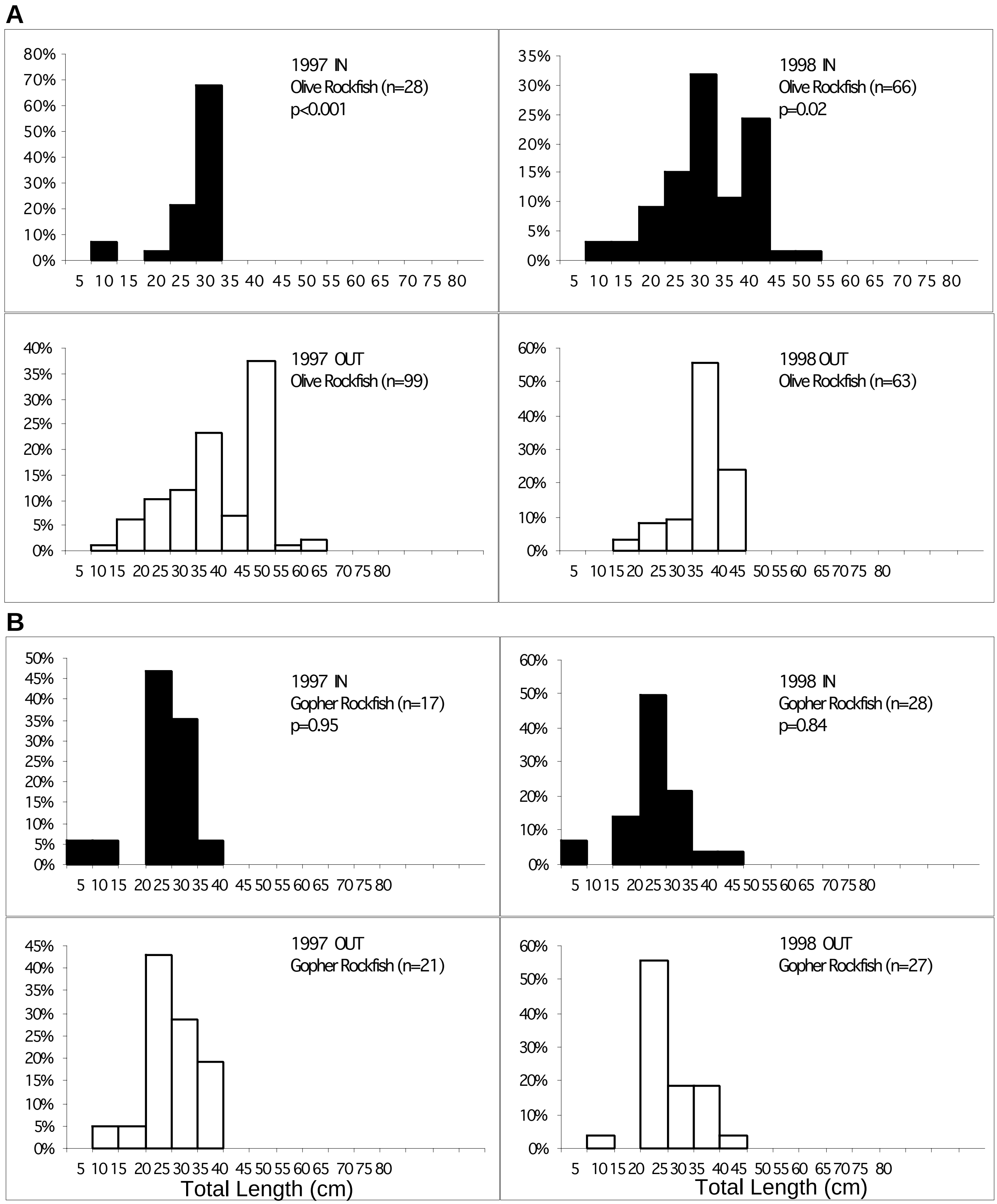

FIGURE 15. Percent frequency distributions of total length of (A) olive and (B) gopher rockfishes inside (black) and outside (white) the Big Creek Ecological Reserve in depths 20–100m in 1997 and 1998. P values are from Kolmogorov-Smirnov goodness of fit comparisons between sizes in and out of reserve.

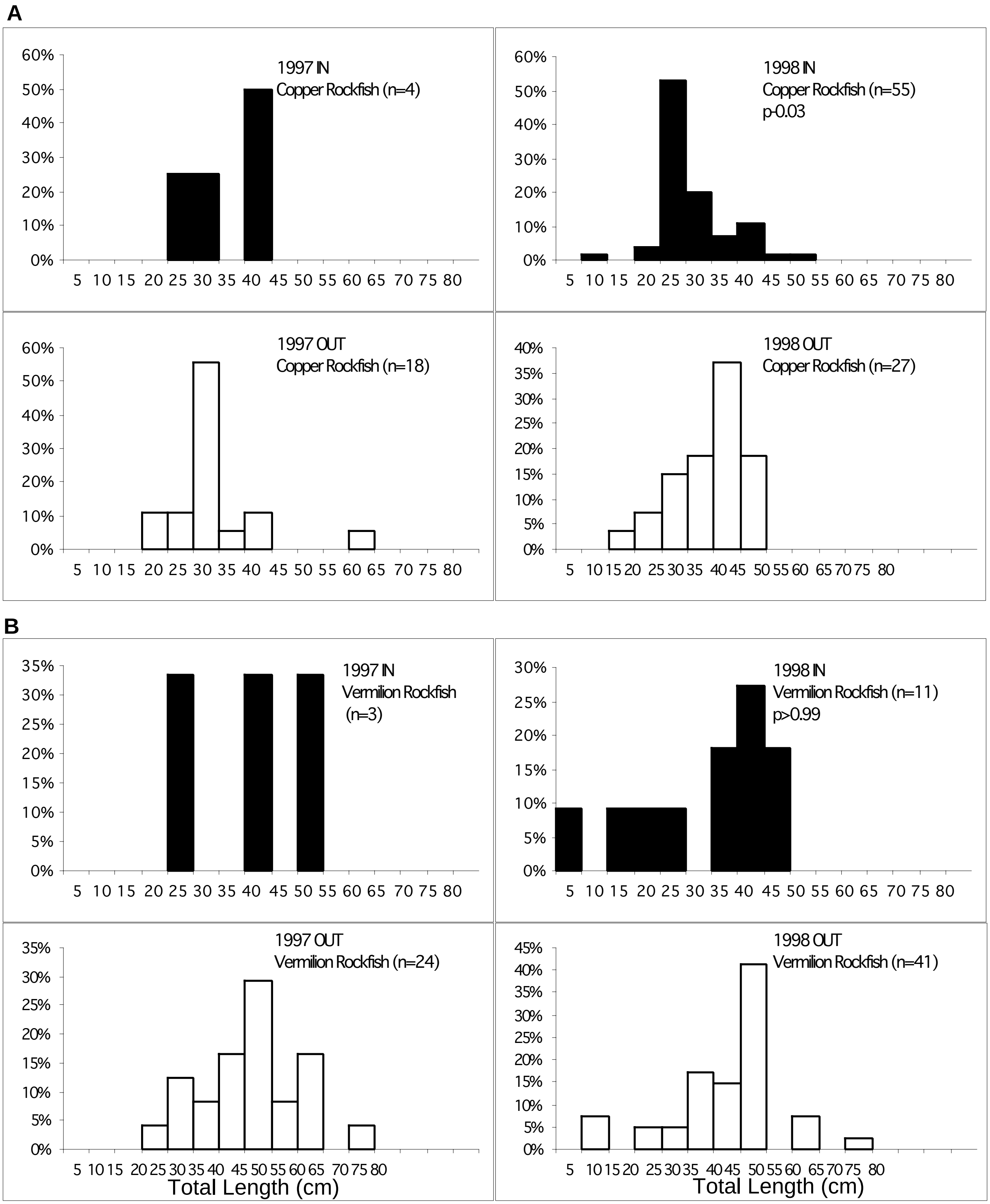

FIGURE 16. Percent frequency distributions of total length of (A) copper and (B) vermilion rockfishes inside (black) and outside (white) the Big Creek Ecological Reserve at depths 20-100 m in 1997 and 1998. P values are from Kolmogorov-Smirnov goodness of fit comparisons between sizes in and out of reserve. No comparisons of copper or vermilion rockfish lengths were made in 1997 due to low sample size inside.

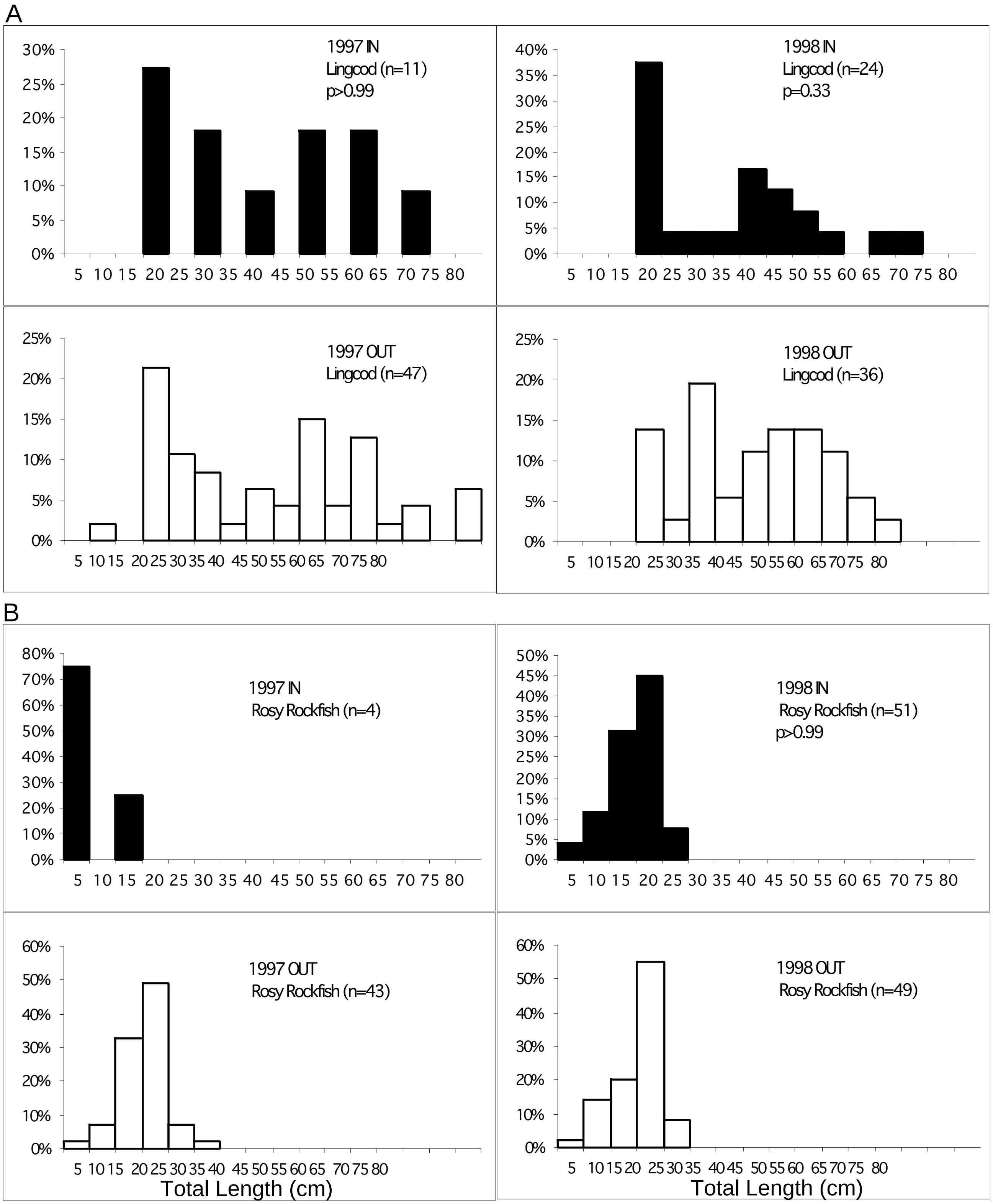

FIGURE 17. Percent frequency distributions of total length of (A) lingcod and (B) rosy rockfishes inside (black) and outside (white) the Big Creek Ecological Reserve at depths 20–100 m in 1997 and 1998. P values are from Kolmogorov-Smirnov goodness of fit comparisons between sizes in and out of reserve. No comparison of rosy rockfish lengths was smade in 1997 due to low sample size.

Tables

TABLE 1. Distribution of submersible dives and quantitative video transects conducted in the Big Creek area during 1997 and 1998.

	Inside BCER		Adjacent to BCER						Total	
			NORTH		SOUTH		WEST			
	1997	1998	1997	1998	1997	1998	1997	1998	1997	1998
No. of Dives[1]	5	5	8	13	7	5	1	1	21	24
No. of Transects										
Depth Range										
<35m	6	5	4	7	2	0			12	12
36–100m	11	17	10	21	9	7			30	45
101–135m			2	3	3	0	1	1	6	4
>135m			9	11	7	6			16	17
Total No.	17	22	25	42	21	13	1	1	64	78

[1] Transects were conducted on 43 dives, but two dives included transects both inside and outside BCER.

TABLE 2. Amount of each substratum type (km^2 and percent area) surveyed by sidescan sonar and direct observations from submersible, in the Big Creek Ecological Reserve (BCER), to the north and south of BCER in <100 m water depth, and in water >100 m adjacent to BCER.

	BCER		**Deep (>100 m)**	
Substratum Type	**km²**	**%**	**km²**	**%**
Fine Sediment	0.02	0.5	4.37	90.4
Sand	3.08	63.6	0.01	0.1
Coarse Sediment	0.99	20.5	0.14	3.0
Boulders	0.01	0.2	0.00	0.1
Rock Outcrop	0.55	11.5	0.29	5.9
Rock/Sediment	0.05	1.1	0.02	0.4
Sediment Ripples	0.13	2.7	-	-
Total Area	4.84		4.83	

	North (<100 m)		**South (<100 m)**	
Substratum Type	**km²**	**%**	**km²**	**%**
Fine Sediment	0.07	1.0	0.10	1.4
Sand	1.49	19.7	2.70	36.6
Coarse Sediment	4.68	61.6	3.60	48.9
Boulders	0.03	0.3	0.08	1.1
Rock Outcrop	0.56	7.3	0.49	6.7
Rock/Sediment	0.10	1.3	0.18	2.5
Sediment Ripples	0.67	8.8	0.21	2.8
Total Area	7.60		7.37	

TABLE 3a. Total number (n), relative (%) and rank abundance of fish taxa observed from the *Delta* submersible inside BCER during fall 1997 and 1998. Data are ordered by total number from 1997.

	1997			1998		
Species	**n**	**%**	**Rank**	**n**	**%**	**Rank**
Sebastes spp. (YOY)[1]	8235	64.6	**1**	2044	16.5	**3**
Sebastes semicinctus (YOY)[1]	2236	17.5	**2**	667	5.4	**5**
Sebastes mystinus	918	7.2	**3**	755	6.1	**4**
Citharichthys stigmaeus	359	2.8	**4**	65	0.5	12
Sebastes wilsoni	200	1.6	**5**	118	1.0	**9**
Aulorhynchus flavidus	153	1.2	**6**			
Rhinogobiops nicholsii	146	1.1	**7**	127	1.0	**8**
Oxylebius pictus	115	0.9	**8**	73	0.6	11
Citharichthys sordidus	91	0.7	**9**	52	0.4	16
Sebastes serranoides	73	0.6	**10**	89	0.7	**10**
Pleuronectiformes	37	0.3	11	21	0.2	20
Sebastes carnatus	23	0.2	12	33	0.3	18
Sebastes spp.	18	0.1	13	343	2.8	**6**
Pisces	18	0.1	13	248	2.0	**7**
Sebastomus spp.[2]	16	0.1	15	55	0.4	15
Embiotoca lateralis	15	0.1	16	5	<0.1	32
Ophiodon elongatus	13	0.1	17	25	0.2	19
Sebastes semicinctus	12	0.1	18	3938	31.8	**1**
Damalichthys vacca	9	0.1	19	4	<0.1	37
Embiotocidae	9	0.1	19	3	<0.1	38
Cottidae	9	0.1	19			
Hexagrammos decagrammus	8	0.1	22	5	<0.1	32
Sebastes caurinus	6	0.1	23	59	0.5	13
Sebastes atrovirens	6	0.1	23	6	0.1	31
Sebastes rosaceus	4	<0.1	25	58	0.5	14
Citharichthys spp.	4	<0.1	25	17	0.1	23
Semicossyphus pulcher	4	<0.1	25	7	0.1	27
Sebastes miniatus	3	<0.1	28	13	0.1	24
Enophrys taurina	2	<0.1	29	5	<0.1	32
Zalembius rosaceus	2	<0.1	29	5	<0.1	32
Sebastes pinniger	2	<0.1	29	1	<0.1	47
Lepidopsetta bilineata	2	<0.1	29			
Oxyjulis californica	2	<0.1	29			
Phanerodon atripes	1	<0.1	34	7	0.1	27
Embiotoca jacksoni	1	<0.1	34	1	<0.1	47
Pleuronichthys spp.	1	<0.1	34	1	<0.1	47
Hypsopsetta guttulata	1	<0.1	34			
Parophrys vetulus	1	<0.1	34			
Sebastes melanops	1	<0.1	34			

Continued

Table 3a continued

Species	1997 n	1997 %	1997 Rank	1998 n	1998 %	1998 Rank
Sebastes jordani[3]				3416	27.5	**2**
Sebastes paucispinis				38	0.3	17
Zaniolepis spp.				20	0.2	21
Zaniolepis latipinnis				18	0.2	22
Agonidae				8	0.1	25
Sebastes crameri (YOY)[1]				8	0.1	25
Sebastes crameri				7	0.1	27
Sebastes hopkinsi				7	0.1	27
Sebastes carnatus/caurinus[4]				5	<0.1	32
Argentina sialis				3	<0.1	38
Lyopsetta exilis				3	<0.1	38
Phanerodon furcatus				3	<0.1	38
Sebastes ruberrimus				3	<0.1	38
Hydrolagus colliei				2	<0.1	43
Sebastes flavidus				2	<0.1	43
Sebastes saxicola				2	<0.1	43
Zaniolepis frenata				2	<0.1	43
Micrometrus minimus				1	<0.1	47
Raja spp.				1	<0.1	47
Rathbunella alleni				1	<0.1	47
Scorpaenichthys marmoratus				1	<0.1	47
Sebastes chlorostictus				1	<0.1	47
Sebastes ensifer				1	<0.1	47
Total number of fishes	12756			12403		
Total number of rockfishes	11753 (92%)			11669 (94%)		
Minimum number of taxa	30			44		
Minimum number of rockfish species	11			19		

[1] Young-of-the-year (YOY)

[2] Rockfishes within the *Sebastomus* complex off Central California comprise seven species that are difficult to discern without close examination.

[3] Likely *S. jordani* but some could be juvenile *S. goodei*

[4] These two similar-looking species are sometimes difficult to discern underwater.

TABLE 3b. Total number (n), relative (%) and rank abundance of fish taxa observed from the *Delta* submersible north and south of BCER during fall 1997 and 1998. Data are ordered by total number from 1997 north.

	North of BCER						South of BCER					
	1997			1998			1997			1998		
Species	**n**	**%**	**Rank**	**n**	**%**	**Rank**	**n**	**%**	**Rank**	**n**	**%**	**Rank**
Sebastes spp. (YOY)[1]	7223	64.4	**1**	11846	74.9	**1**	8001	80.9	**1**	551	45.8	**1**
Sebastes semicinctus (YOY)[1]	1052	9.4	**2**	154	1.0	**8**	20	0.2	11	11	0.9	14
Sebastes mystinus	474	4.2	**3**	311	2.0	**5**	1255	12.7	**2**	26	2.2	**8**
Sebastes hopkinsi	459	4.1	**4**	383	2.4	**4**				12	1.0	11
Sebastes spp.	439	3.9	**5**	991	6.3	**2**	12	0.1	18	186	15.4	**2**
Citharichthys spp.	285	2.5	**6**	45	0.3	14	26	0.3	**9**			
Sebastes semicinctus	214	1.9	**7**	195	1.2	**7**	30	0.3	**8**	175	14.5	**3**
Cololabis saira	200	1.8	**8**									
Sebastes wilsoni	134	1.2	**9**	747	4.7	**3**						
Phanerodon atripes	100	0.9	**10**				32	0.3	**7**			
Sebastes entomelas	81	0.7	11	298	1.9	**6**	2	<.01	25			
Sebastes serranoides	59	0.5	12	46	0.3	13	141	1.4	**3**	44	3.7	**5**
Citharichthys stigmaeus	58	0.5	13	137	0.9	**10**	23	0.2	**10**	1	0.1	19
Sebastes rosaceus	51	0.5	14	62	0.4	11	15	0.2	16	20	1.7	**9**
Zaniolepis spp.	41	0.4	15									
Citharichthys sordidus	40	0.4	16	57	0.4	12						
Zalembius rosaceus	37	0.3	17	11	0.1	24						
Pleuronectiformes	36	0.3	18	40	0.3	15	6	0.1	19	1	0.1	19
Ophiodon elongatus	34	0.3	19	35	0.2	19	20	0.2	11	5	0.4	15
Oxylebius pictus	21	0.2	20	39	0.2	16	108	1.1	**4**	29	2.4	**7**
Pisces	19	0.2	21	35	0.2	19	15	0.2	16	12	1.0	11
Sebastes jordani[2]	17	0.2	22	2	<.01	39						
Damalichthys vacca	16	0.1	23	3	<.01	36	5	0.1	20	1	0.1	19
Sebastomus spp. [3]	15	0.1	24	38	0.2	17	16	0.2	14	4	0.3	16
Sebastes miniatus	14	0.1	25	37	0.2	18	17	0.2	13	13	1.1	**10**
Sebastes caurinus	14	0.1	25	35	0.2	19	5	0.1	20	4	0.3	16
Rhinogobiops nicholsii	12	0.1	27	147	0.9	**9**	40	0.4	**6**	53	4.4	**4**
Cottidae	9	0.1	28	3	<.01	36	3	<.01	24	1	0.1	19
Sebastes carnatus	8	0.1	29	23	0.2	22	16	0.2	14	12	1.0	11
Semicossyphus pulcher	6	0.1	30				5	0.1	20			
Sebastes saxicola	6	0.1	30									
Embiotoca jacksoni	5	<.01	32	1	<.01	45	2	<.01	25			
Enophrys taurina	4	<.01	33	11	0.1	24						
Sebastes paucispinis	4	<.01	33	3	<.01	36						
Sebastes pinniger	3	<.01	35	6	<.01	28	1	<.01	28	3	0.3	18
Embiotocidae	3	<.01	35	1	<.01	45	4	<.01	23			
Oxyjulis californica	3	<.01	35				64	0.7	**5**	36	3.0	**6**
Argentina sialis	2	<.01	38	16	0.1	23						
Hexagrammos decagrammus	2	<.01	38	4	<.01	32	2	<.01	25	1	0.1	19
Icelinus filamentosus	2	<.01	38	1	<.01	45						
Zaniolepis latipinnis	1	<.01	41	7	<.01	27						
Agonidae	1	<.01	41	6	<.01	28	1	<.01	28			
Pleuronichthys spp.	1	<.01	41	5	<.01	31	1	<.01	28			
Sebastes ruberrimus	1	<.01	41	4	<.01	32						
Embiotoca lateralis	1	<.01	41	1	<.01	45	1	<.01	28	1	0.1	19
Rathbunella alleni	1	<.01	41	1	<.01	45						
Parophrys vetulus	1	<.01	41									
Sebastes elongatus	1	<.01	41									
Psettichthys melanostictus				9	0.1	26						
Sebastes flavidus				6	<.01	28						
Lyopsetta exilis				4	<.01	32						
Synodus lucioceps				4	<.01	32						

Continued

Table 3b continued

Species	North of BCER 1997 n	%	Rank	1998 n	%	Rank	South of BCER 1997 n	%	Rank	1998 n	%	Rank
Anarrichthys ocellatus				2	<.01	39						
Glyptocephalus zachirus				2	<.01	39						
Microstomus pacificus				2	<.01	39						
Sebastes helvomaculatus				2	<.01	39						
Sebastes rufus				2	<.01	39						
Icelinus tenuis				1	<.01	45						
Sebastes chlorostictus				1	<.01	45						
Sebastes constellatus				1	<.01	45						
Sebastes serriceps				1	<.01	45						
Symphurus atricauda				1	<.01	45						
Torpedo californica				1	<.01	45						
Sebastes miniatus/pinniger[4]							1	<.01	28			
Sebastes nebulosus							1	<.01	28			
Hydrolagus colliei										1	0.1	19
Sebastes carnatus/caurinus[4]										1	0.1	19
Total number of fishes	11210			15826			9891			1204		
Total number of rockfishes	10269	(92%)		15194	(96%)		9533	(96%)		1062	(88%)	
Minimum number of taxa	38			46			24			19		
Minimum number of rockfish species	16			20			10			9		

[1] Young-of-the-year (YOY)
[2] Likely *S. jordani* but some 1998 could be juvenile *S.goodei*
[3] Rockfishes within the Sebastomus complex off Central California comprise seven species that are difficult to discern without close examination.
[4] These two similar-looking species are sometimes difficult to discern underwater.

TABLE 3c. Total number (n), relative (%) and rank abundance of fish taxa observed from the *Delta* submersible at depths >100m outside BCER during fall 1997 and 1998.

Species	1997 n	1997 %	1997 Rank	1998 n	1998 %	1998 Rank
Merluccius productus	1098	23.8	**1**	6	0.3	34
Sebastes jordani[1]	1007	21.8	**2**	201	9.2	**3**
Sebastes spp.	297	6.4	**3**	224	10.3	**2**
Sebastes semicinctus	232	5.0	**4**	114	5.2	**7**
Sebastes wilsoni	207	4.5	**5**	356	16.3	**1**
Pleuronectiformes	206	4.5	**6**	141	6.5	**4**
Sebastomus spp. [2]	173	3.7	**7**	127	5.8	**5**
Sebastes miniatus/pinniger[3]	155	3.4	**8**			
Sebastes saxicola	118	2.6	**9**	20	0.9	20
Agonidae	95	2.1	**10**	93	4.3	**8**
Sebastes crameri	92	2.0	11	28	1.3	17
Sebastes spp. (YOY)[4]	88	1.9	12	15	0.7	25
Argentina sialis	83	1.8	13	42	1.9	16
Sebastes helvomaculatus	77	1.7	14	68	3.1	**9**
Sebastes elongatus	71	1.5	15	47	2.2	15
Sebastes chlorostictus	67	1.5	16	67	3.1	11
Sebastes entomelas	64	1.4	17	2	0.1	42
Microstomus pacificus	54	1.2	18	61	2.8	13
Zoarcidae	44	1.0	19	24	1.1	18
Citharichthys spp.	44	1.0	19			
Lyopsetta exilis	38	0.8	21	15	0.7	25
Sebastes paucispinis	35	0.8	22	8	0.4	31
Pisces	34	0.7	23	125	5.7	**6**
Citharichthys sordidus	31	0.7	24	5	0.2	36
Hydrolagus colliei	23	0.5	25	12	0.5	29
Sebastes hopkinsi	22	0.5	26	24	1.1	18
Zalembius rosaceus	20	0.4	27	18	0.8	21
Sebastes rufus	18	0.4	28	58	2.7	14
Zaniolepis spp.	17	0.4	29	14	0.6	27
Glyptocephalus zachirus	16	0.3	30	65	3.0	12
Sebastolobus spp.	10	0.2	31			
Ophiodon elongatus	9	0.2	32	14	0.6	27
Sebastes rosenblatti	9	0.2	32	8	0.4	31
Lycodes cortezianus	9	0.2	32	7	0.3	33
Sebastes pinniger	8	0.2	35	1	0.0	49
Sebastes ruberrimus	7	0.2	36	11	0.5	30
Zaniolepis latipinnis	6	0.1	37	16	0.7	23
Sebastes zacentrus	5	0.1	38	68	3.1	**9**
Rajiformes-egg cases	5	0.1	38			
Cottidae	4	0.1	40	18	0.8	21

Continued

Table 3c continued

Species	1997 n	%	Rank	1998 n	%	Rank
Eptatretus stoutii	4	0.1	40	4	0.2	38
Chilara taylori	3	0.1	42	2	0.1	42
Sebastes ovalis	2	<0.1	43	1	0.1	49
Stichaeidae	2	<0.1	43	1	0.1	49
Xeneretmus spp.	2	<0.1	43			
Enophrys taurina	1	<0.1	46	6	0.3	34
Sebastes constellatus	1	<0.1	46	4	0.2	38
Sebastes levis	1	<0.1	46	2	0.1	42
Sebastolobus alascanus	1	<0.1	46	2	0.1	42
Porichthys notatus	1	<0.1	46	1	0.1	49
Raja spp.	1	<0.1	46	1	0.1	49
Pleuronichthys spp.	1	<0.1	46			
Raja inornata	1	<0.1	46			
Sebastes ensifer				16	0.7	23
Sebastes diploproa				5	0.2	36
Zaniolepis frenata				4	0.2	38
Sebastes miniatus				3	0.1	41
Anoplopoma fimbria				2	0.1	42
Sebastes nigrocinctus				2	0.1	42
Synodus lucioceps				2	0.1	42
Icelinus filamentosus				1	0.1	49
Parophrys vetulus				1	0.1	49
Sebastes babcocki				1	0.1	49
Sebastes gilli				1	0.1	49
Total number of fishes	4619			2185		
Total number of rockfishes	2756 (60%)			1482 (68%)		
Minimum number of taxa	39			49		
Minimum number of rockfish species	19			25		

[1] Likely *S. jordani* but some in 1998 could be juvenile *S.goodei*

[2] Rockfishes within this complex off central California comprise seven species that are difficult to discern without close examination.

[3] These two similar-looking species are sometimes difficult to discern underwater.

[4] Young-of-the-year (YOY)

TABLE 4. Total amount of area (m^2) surveyed during quantitative transects inside, and to the north, south and west of BCER, in four depths and three habitat types.

		INSIDE			NORTH			SOUTH			Total
Year	Depth (m)	rock	mixed	soft	rock	mixed	soft	rock	mixed	soft	
1997	<35	1287	52	693	618	283	748	183	68	599	4529
	35-100	1019	654	2530	835	1011	1980	1411	1262	1339	12040
	100-135				24	257	717	226	389	726	2339
	>135				1600	293	1753	940	232	1653	6472
1998	<35	1244	192	779	579	390	1332				4517
	35-100	1488	377	3587	1313	128	6156	973	625	959	15606
	100-135						1805			385	2189
	>135				2188	182	1905	562	148	1505	6490
	Total	5038	1274	7589	7157	2544	16395	4295	2723	7166	54182

TABLE 5. Results of ANOVA and Tukey Post Hoc Multiple Comparison (with Kramer's modification) of fish density (# fish/m^2) in 1997.

Location:	North	Inside	South
Substrata:	Rock	Mixed	Soft
Depth:	1 = <35 m	2 = 35—100 m	

ANALYSIS OF VARIANCE

Source	Sum-of-Squares	DF	Mean-Square	F-ratio	**P**
Location	0.024	2	0.012	0.546	0.580
Substrata	0.553	2	0.276	12.825	**0.000**
Depth	0.011	1	0.011	0.516	0.474
Location * Substrata	0.041	4	0.010	0.474	0.755
Location * Depth	0.022	2	0.011	0.507	0.603
Substrata * Depth	0.008	2	0.004	0.187	0.829
Depth * Substrata* Location	0.001	4	0.000	0.017	0.999
Error	3.622	68	0.022		

T**ukey Post Hoc Multiple Comparison** (w/ Kramer modification) to test fish density among substrata categories.

Rock	Mixed	Soft

TABLE 6. Results of ANOVA and Tukey Post Hoc Multiple Comparison (with Kramer's modification) of fish density (# fish/m^2) at depths 35–100 m.

Location:	North	Inside	South
Substrata:	Hard	Mixed	Soft
Year:	1997	1998	

ANALYSIS OF VARIANCE

Source	Sum-of-Squares	DF	Mean-Square	F-ratio	P
Location	0.089	2	0.044	1.587	0.207
Substrata	1.902	2	0.951	34.010	**0.000**
Year	0.080	1	0.080	2.848	0.093
Location* Substrata	0.415	4	0.104	3.707	**0.006**
Location* Year	0.048	2	0.024	0.851	0.428
Substrata * Year	0.177	2	0.088	3.156	**0.045**
Year * Substrata* Location	0.657	4	0.164	5.870	**0.000**
Error	6.040	216	0.028		

Tukey Post Hoc Multiple Comparison (w/ Kramer modification) to test fish density among substrata categories.

Hard	Mixed	Soft

TABLE 7. Two-factor Analysis of Variance comparing fish density (#fish/m^2) of economically valuable species (i.e., blue, olive, vermilion, canary, gopher, copper, and yellowtail rockfish and lingcod) on high relief rock substratum among three locations (north, south, and inside BCER) and two years (1997 and 1998).

ANALYSIS OF VARIANCE

Source	Sum-of-Squares	DF	Mean-Square	F-ratio	**P**
Location	0.006	2	0.003	0.163	0.850
Year	0.288	1	0.288	14.720	0.000
Location* Year	0.016	2	0.008	0.398	0.673
Error	2.211	113	0.020		

	ADJ. LS MEAN	SE	N
YEAR = 1997	0.137	0.018	66
YEAR = 1998	0.037	0.020	53
LOCATION = inside	0.077	0.020	49
LOCATION = north	0.090	0.025	31
LOCATION = south	0.093	0.023	39

Appendix

APPENDIX 1: Scientific, common, and code names for fish taxa identified within our study sites in and around the Big Creek Ecological Reserve, 1997 and 1998. Names ordered alphabetically by scientific name.

Scientific Name	Code	Common name
Agonidae	AG	poachers
Anarichthys ocelatus	AO	wolf-eel
Anoplopoma fimbria	AF	sablefish
Argentina sialis	AS	Pacific argentine
Aulorhynchus flavidus	AUF	tubesnout
Bathylagidae	BL	deepsea smelts
Bathymasteridae	BA	ronquils
Chilara taylori	CT	spotted cusk-eel
Chitonotus pugetensis	CP	roughback sculpin
Citharichthys sordidus	CS	Pacific sanddab
Citharichthys spp.	CSP	sanddabs
Citharichthys stigmaeus	CST	speckled sanddab
Cololabis saira	COL	Pacific saury
Cottidae	CO	sculpins
Damalichthys vacca	DV	pile surfperch
Echinorhinus cookei	EC	prickly shark
Embiotoca jacksoni	EMJ	black surfperch
Embiotoca lateralis	EML	striped surfperch
Embiotocidae	EMB	surfperches
Enophrys taurina	ET	bull sculpin
Eopsetta jordani	EJ	petrale sole
Eptatretus stoutii	ES	Pacific hagfish
Glyptocephalus zachirus	EZ	rex sole
Hexagrammos decagrammus	HD	kelp greenling
Hexanchus griseus	HG	bluntnose sixgill shark
Hydrolagus colliei	HC	spotted ratfish
Hypsopsetta guttulata	HYG	diamond turbot
Icelinus filamentosus	IF	threadfin sculpin
Icelinus spp.	ISP	Icelinus sculpins
Icelinus tenuis	IT	spotfin sculpin
Lepidopsetta bilineata	LBI	rock sole
Lycodes cortezianus	LC	bigfin eelpout
Lycodes pacificus	LP	blackbelly eelpout
Lyopsetta exilis	LE	slender sole
Merluccius productus	MP	Pacific hake
Micrometrus minimus	MM	dwarf surfperch
Microstomus pacificus	MPA	Dover sole
Odontopyxis trispinosa	OPX	pygmy poacher
Ophiodon elongatus	OE	lingcod
Orthonopias triacis	OT	snubnose sculpin

Appendix 1. (continued)

Scientific Name	Code	Common name
Oxyjulis californica	OC	señorita
Oxylebius pictus	OP	painted greenling
Paralichthys californicus	PC	California halibut
Parophrys vetulus	PV	English sole
Peprilus simillimus	PS	Pacific butterfish
Phanerodon atripes	PHA	sharpnose surfperch
Phanerodon furcatus	PHF	white surfperch
Pisces	UN	unidentified fishes
Plectobranchus evides	PE	bluebarred prickleback
Pleuronectiformes	FL	flatfishes
Pleuronichthys spp.	PSP	turbots
Pleuronichthys verticalis	PVT	hornyhead turbot
Porichthys notatus	PN	plainfin midshipman
Psettichthys melanostictus	PSM	Sand sole
Raja inornata	RI	California skate
Raja rhina	RR	longnose skate
Raja spp.	RSP	skates
Rajiformes-egg cases	SK	skate egg cases
Rathbunella alleni	RS	stripefin ronquil
Rhinogobiops nicholsii	CN	blackeye goby
Scorpaenichthys marmoratus	SCM	cabezon
Scyliorhinidae-egg cases	CE	catshark egg cases
Sebastes atrovirens	SAT	kelp rockfish
Sebastes aurora	SAU	aurora rockfish
Sebastes babcocki	SB	redbanded rockfish
Sebastes carnatus	SCT	gopher rockfish
Sebastes carnatus/caurinus[1]	SCT/SCU	gopher/copper complex
Sebastes caurinus	SCU	copper rockfish
Sebastes chlorostictus	SC	greenspotted rockfish
Sebastes chrysomelas	SCHR	black-and-yellow rockfish
Sebastes constellatus	SCO	starry rockfish
Sebastes crameri	SCR	darkblotched rockfish
Sebastes diploproa	SD	splitnosed rockfish
Sebastes elongatus	SE	greenstriped rockfish
Sebastes ensifer	SEF	swordspine rockfish
Sebastes entomelas	SEN	widow rockfish
Sebastes flavidus	SF	yellowtail rockfish
Sebastes gilli	SGI	bronzespotted rockfish
Sebastes goodei	SG	chilipepper rockfish
Sebastes goodei/jordani[1]	SG/SJ	chilipepper/shortbelly complex
Sebastes helvomaculatus	SH	rosethorn rockfish
Sebastes hopkinsi	SHO	squarespot rockfish
Sebastes jordani	SJ	shortbelly rockfish
Sebastes levis	SL	cowcod

Appendix 1. (continued)

Scientific Name	**Code**	**Common name**
Sebastes maliger	SMA	quillback rockfish
Sebastes melanops	SMP	black rockfish
Sebastes miniatus	SM	vermilion rockfish
Sebastes miniatus/pinniger[1]	SM/SPI	vermilion/canary complex
Sebastes mystinus	SMY	blue rockfish
Sebastes nebulosus	SNE	China rockfish
Sebastes nigrocinctus	SNI	tiger rockfish
Sebastes ovalis	SO	speckled rockfish
Sebastes paucispinis	SP	bocaccio
Sebastes pinniger	SPI	canary rockfish
Sebastes rosaceus	SRC	rosy rockfish
Sebastes rosenblatti	SRO	greenblotched rockfish
Sebastes ruberrimus	SR	yelloweye rockfish
Sebastes rubrivinctus	SRU	flag rockfish
Sebastes rufus	SRF	bank rockfish
Sebastes saxicola	SSA	stripetail rockfish
Sebastes semicinctus	SS	halfbanded rockfish
Sebastes serranoides	SSER	olive rockfish
Sebastes serriceps	SER	treefish
Sebastes spp.	SSP	rockfishes
Sebastes wilsoni	SW	pygmy rockfish
Sebastes zacentrus	SZ	sharpchin rockfish
Sebastolobus alascanus	SAL	shortspine thornyhead
Sebastolobus altivelis	SALT	longspine thornyhead
Sebastolobus spp.	SEB	thornyheads
Sebastomus spp.[2]	ST	Sebastomus rockfishes
Semicossyphus pulcher	SEP	California sheephead
Stichaeidae	STI	pricklebacks
Symphurus atricauda	SYA	California tonguefish
Synodus lucioceps	SLU	California lizardfish
Torpedo californica	TC	Pacific electric ray
Trachurus symmetricus	TS	jack mackerel
Xeneretmus spp.	XS	poacher genus
Zalembius rosaceus	ZR	pink surfperch
Zaniolepis frenata	ZF	shortspine combfish
Zaniolepis latipinnis	ZL	longspine combfish
Zaniolepis spp.	ZSP	combfishes
Zoarcidae	ZO	eelpouts

[1] These similar-looking species are sometimes difficult to discern underwater.

[2] Rockfishes within the *Sebastomus* complex off Central California comprise 7 species that are difficult to discern without close examination.

Part Two

Small-Scale Analysis of Subtidal Fish Assemblages and Associated Habitat Characteristics

off Central California

Abstract

Traditional fishing stocks are declining and as a result conventional management schemes are being reevaluated. The Magnuson-Stevens Act requires fishery managers to identify and designate Essential Fish Habitat (EFH) for the intent of conservation. To distinguish EFH, the effects of habitat on fish ecology must be understood. Once this relationship has been classified, remote-sensing technology can be used to map subtidal areas. After EFH has been identified, marine reserves can be designated for threatened species.

For this section of the project, we surveyed the near-shore (20–100 m) waters off Central California to assess the fish guilds associated with distinct habitats. A multivariate ordination produced two significant guilds among five fish species (*Sebastes mystinus*, *S. serranoides*, *S. carnatus*, *Citharichthys stigmaeus*, and *Oxylebius pictus*) and distinct habitat variables. Four fish species (*Ophiodon elongatus*, *S. mystinus*, *S. semicinctus*, and *S. chlorostictus*) were examined to analyze the relationship between fish species and habitat characteristics and to derive an index of habitat electivity. *S. mystinus*, *S. chlorostictus, and S. semicinctus* were significantly correlated with different habitats including seafloor type, depth, slope, and habitat area. *O. elongatus* did not have any significant relationships with distinct habitats, but several of the above habitats were identified as important.

Introduction

The structural complexity of a habitat has direct (e.g., refuge [Sih et al. 1985]) and indirect (e.g., effects on prey distributions and foraging abilities [Ebeling and Laur 1985]) influences on the distribution and abundance of fishes (Potts and Hulbert 1994, Friedlander and Parrish 1998, Jenkins and Wheatley 1998). This relationship between fishes and habitat structure must be studied at a scale appropriate to the organism and the processes of interest (Addicott et al. 1987, Sale 1998). Greene et al. (1999) recently suggested that macro-scale (one to tens of meters) and micro-scale (features representing <1 m of horizontal area) may be appropriate for studying demersal fish habitat. In this section, we use multivariate techniques to: 1) group fish species and their macro- and micro-scale habitats into guilds; 2) analyze the relationship between selected fish species and their macro- and micro-scale habitats; and 3) derive an index of habitat electivity for selected fish species, in the vicinity of the Big Creek Ecological Reserve (BCER), Central California.

Analysis and Statistical Methods

Only data from the 1997 submersible surveys, inside and near the border of the BCER in water depths of 20–100 m, were used in this analysis to avoid inter-annual variation in habitat use and species assemblages and potential biases from the effect of fishing. Each video transect was subdivided into habitat patches. A habitat patch was identified by a distinct and recognizable change in seafloor type. Seafloor type, slope, depth, and patch length were the independent variables used to describe habitat in our analyses. Seafloor type was described by a combination of primary (>50% of the area) and secondary (>20% of the area) substrata of a patch. Seafloor type consisted of six different substratum categories (fine sediment or sand, shell hash, or coarse sand, cobble, boulder, rock, and organic features); these are defined by the substratum texture or grain size (see Greene et al. 1999). Fine sediment or sand seafloor type comprised grains < 2 mm, shell hash or coarse sand had a grain size 2–4 mm, cobble included grains of 64–256 mm, boulders were composed 0.25–3.0 m, and rock was >3 m or was exposed bedrock. Organic seafloor types were classified by the principal biological material that covered the substratum, including understory algae (Laminariales, Desmarestiales, and foliose reds), canopy forming algae (*Macrocystis pyrifera* and *Nereocystis lutkeana*), anemones (*Metridium* spp.), hydrocorals (*Stylaster californicus*), and sea pens (primarily *Stylatula* spp.). For example, a habitat patch was described as rock-organic if it comprised at least 50% rock substratum and at least 20% organic seafloor type. Slope was estimated as the degree of inclination of the seafloor, that is flat (0–5°), low (5–30°), or high (>30°). For example, a habitat comprising at least 50% high slope and at least 20% flat slope was described as high-flat. Patch length was estimated by counting the number of laser intervals (20 cm per interval) over segments of the transect. Depth of each habitat patch was measured to the nearest meter by a sensor located on the submersible.

Multivariate Ordination

A multivariate model was generated to group fish and habitat data into guilds. We define a guild as a group of species that is found in the same habitat and likely sharing the same resource base (after Yoklavich et al. 2000; see also Cailliet et al. 1999; Root 1967). Traditional multivariate models, like canonical correlation analysis, require continuous data. Because our data set contained continuous (i.e., depth and patch length) and categorical (i.e., seafloor type and slope) data, we created a model in a manner similar to a canonical correlation analysis. All fish species and habitat variables were considered in this analysis.

Species and habitat data were organized into separate matrices containing presence and absence data. Within each matrix, each patch was compared to all others using Sorensen's similarity coefficient on MVSP version 3.0 (Kovach 1998). Multi-Dimensional Scaling (MDS; SPSS version 10.0 [1999]) was used for both similarity matrices to detect underlying dimensions that explain distances between samples (Statsoft 1999). The species and habitat dimensions generated from MDS were compared using Pearson's product-moment correlation, equivalent to a canonical correlation (Tabachnik and Fidell 1989). Any statistically significant ($p<0.05$) correlations between MDS dimensions were considered as canonical root pairs. To interpret the canonical root pairs, the dimensions were compared with the raw data using Pearson's correlation. Variables with correlations greater than 0.30 were used to interpret the roots (Tabachnik and Fidell 1989). The scores from canonical root pairs were plotted and the axes were labeled with variables selected to interpret the roots.

Logistic Regression

Logistic regression was used to examine the relationship between binary species data (presence or absence) and categorical (seafloor type and slope) and continuous (depth and patch length) habitat data (Trexler and Travis 1993). Four species were selected for the analysis, *Sebastes mystinus* (blue rockfish), *Ophiodon elongatus* (lingcod), *S. semicinctus* (halfbanded rockfish), and *S. chlorostictus* (greenspotted rockfish). *Sebastes mystinus* and *S. semicinctus* were selected because they were the most abundant species (Table 1), ranking 2 and 8 respectively. *Ophiodon elongatus* was selected because there is concern regarding declining population biomass (Adams et al. 1999) and it is being considered for protection with marine reserves (Parrish et al. 2000). *Sebastes chlorostictus* was selected because previous research suggested that this species has relatively broad habitat affinities (Yoklavich et al. 2000).

Habitat data were included in the analysis only if a fish species occurred at least once on a specific seafloor type. Depth, patch length, and slope associated with each seafloor type were also included in the analysis. The fish and habitat relationship was estimated as a binomial distribution where the probability of species presence increases or decreases as a sigmoid function of the habitat variables. The rate of increase or decrease of the sigmoid curve was measured by the parameter β.

Correlations among seafloor type, slope, depth, and patch length were tested using Spearman's rank correlation (SPSS version 10.0) because the data were binary and nonlinear (Krebs 1999). Correlated independent variables ($r> 0.60$) were removed from the analysis. Additionally, habitat variables were removed if logistic regression could not compute residual chi-squares due to redundancies. The best-fit logistic regression model was selected based on significance of the model ($p<0.05$).

Index of Habitat Electivity

An Index of Habitat Electivity (IHE) was developed to illustrate habitat affinity for the four fish species used in the logistic regression analysis. IHE is a ratio of the percent frequency of occurrence of a fish species (%FO spp) to the amount of available habitat. IHE was calculated individually for each seafloor type. Available habitat is the sum of its percent area (%A) and percent frequency (%FO) of patch occurrence. IHE is calculated for each seafloor type using the following equation:

$$\%IHE = \left(\frac{\%FOspp}{\%A+\%FO}\right)$$

where:

$$\%FOspp = \left(\frac{\#\text{ of occurrences within a seafloor type}}{\text{Total occurrences in all seafloor types}}\right) * 100$$

and

$$\%A = \left(\frac{\text{Area of seafloor type}}{\text{Total area of all seafloor types}}\right) * 100$$

and

$$\%FO = \left(\frac{\text{Number of patches of seafloor type}}{\text{Total number of patches}}\right) * 100$$

The resulting values can be used to rank each seafloor type according to species-occurrence and availability. The highest values represent seafloor types with lower availability and high species-occupancy, and the lowest values represent seafloor types of high availability and low species-occupancy. For each seafloor type, the frequency of occurrence of a species and the amount of available type were graphed as a dual histogram, with the former plotted on the right side and the latter plotted on the left side. IHE values also were plotted as a scale bar on the right side of the graph.

Results

Information collected during ten submersible dives made in and near the BCER in 1997 was used in these analyses. Twenty-six unique seafloor types were identified from 232 habitat patches in water depths 20–100 m. The total area surveyed was 6,319 m^2. Patches of seafloor type (i.e., our samples) ranged in size from <1 to 261 m^2 (mean = 27.2, S.D. = 48.2; Figure 1). The dominant seafloor type was hash-hash, 1,658 m^2 (26% of total; Figure 2). Sand-sand was the second most common seafloor type (1204 m^2, 19% of the total).

A total of 16,309 fishes was identified to the lowest possible taxon and represented 70 taxa, including 56 species (Table 1). Rockfishes (N=14,162) accounted for 87% of the total fishes. Young-of-the-year (YOY) rockfishes accounted for 74% of the rockfishes (10,503 fishes).

Multivariate Ordination

The canonical correlation analysis of all the data produced only one significant relationship among five fish species and ten habitat variables (Figure 3). The analysis identified three guilds of fishes. Guild A was comprised *Oxylebius pictus* (painted greenling), *Sebastes serranoides* (olive rockfish), *S. mystinus*, and *S. carnatus* (gopher rockfish), and inhabited high relief rocky areas in shallow (<35 m) water. Guild B was represented by only one species, *Citharichthys stigmaeus* (speckled sanddab), which inhabited coarse grain sand waves in deep (>35 m) water. A third guild (C) was a mix of species from guild A and B, including *C. stigmaeus*, *O. pictus*, and *S. mystinus*; these occupied a mix of rock and sand habitats in shallow (< 35 m) water.

Logistic Regression and IHE

The logistic regression for *Sebastes mystinus* included 14 seafloor types, patch length, and depth, but not slope, and produced a best-fit model that retained five seafloor types and depth (Table 2). *Sebastes mystinus* was positively and significantly correlated with organic-rock patches, and significantly negatively correlated with hash-hash and hash-organic patches and depth. Nine seafloor types (Boulder-sand, Hash-cobble, Boulder-hash, Boulder-boulder, Organic-rock, Rock-boulder, Boulder-organic, Rock-organic, and Organic-hash) had IHE values >1.0 (1.2–4.1; Figure 4a), indicating that *S. mystinus* associated with these seafloor types. Hash-hash, Hash-organic, Hash-rock, and Rock-hash had low IHE values (0.05–0.5), indicating that *S. mystinus* avoided these seafloor types.

The logistic regression model for *Ophiodon elongatus* included nine seafloor types, patch length, slope, and depth. The best-fit model removed all seafloor types, slope, and depth (Table 2). The presence of *O. elongatus* was positively and significantly correlated with patch length. Five seafloor types (Boulder-boulder, Organic-rock, Rock-boulder, Rock-hash, and Sand-rock) had IHE values >1.0 (1.2–2.7; Figure 4b). Three seafloor types (Rock-organic, Sand-sand, and Rock-sand) had low (<1) IHE values (0.3– 0.6).

The logistic regression for *Sebastes semicinctus* included six seafloor types, patch length, slope, and depth. *Sebastes semicinctus* was positively and significantly correlated with sand-rock and rock-sand patches, slope, patch length, and negatively correlated with water depth (Table 2). Sand-rock and rock-sand had IHE vales >1.0 (Figure 4c); Rock-rock, Hash-organic, Sand-sand, and Sand-organic had IHE values <1.0 (0.5 to 0.9).

The logistic regression for *Sebastes chlorostictus* included five seafloor types, patch length, slope, and depth. The best-fit model retained three seafloor types, patch length, slope, and depth (Table 2). *Sebastes chlorostictus* was significantly and positively correlated with rock-sand and sand-rock patches, and patch length. Depth and slope were not significant factors. However, this species only occurred in water depths >100m, so depth could not be a significant factor. Rock-sand and Sand-rock had IHE values >1.0 (2.7 and 2.4; Figure 4d), and Sand-sand had a low IHE values (0.2).

Discussion

For marine subtidal fishes, habitat can function as a source of food (Foster and Schiel 1985, Ralston et al. 1986), refuge from environmental stresses or predators (Sih et al. 1985, Friedlander and Parrish 1998), recruitment sites (Ebeling and Laur 1985, Carr 1994), and spawning and mating areas (Balon 1985). Rockfishes (*Sebastes* spp.) have remarkable specificity to benthic structural features (Larson and DeMartini 1983, Holbrook *et al.* 1990, Yoklavich et al. 2000). These structural features need to be assessed at scales that are relevant to the organisms and the processes of interest (Sale 1998).

From the logistic regression analysis, three species (*O. elongatus*, *S. semicinctus*, and *S. chlorostictus*) were more likely to occur in larger habitat patches. This likely is an artifact of sampling, where the probability of encountering a species increases with a larger sample size (Angermeier and Schosser 1989). *Sebastes mystinus* and *S. semicinctus* had negative associations with depth, which agrees with known depth distributions (near the surface to 549 m, and 58 to 402 m, respectively; Eschmeyer et al. 1983). *Ophiodon elongatus* and *S. chlorostictus* did not have significant associations with depth. *Ophiodon elongatus* migrates seasonally for spawning and generally stays in water less than 200 m (Cass et al. 1990). *Sebastes chlorostictus* never occurred in shallow water in the 1997 survey and generally lives in deep waters (49 to 201 m) (Eschmeyer et al. 1983).

There was also a very evident pattern of *S. semicinctus* and *S. chlorostictus* occurring on mixed habitat edges (i.e., Rock-sand) as opposed to one seafloor type (i.e., Rock-rock). Both of these species have been associated with mixed seafloor macro-scale habitats in previous research (Yoklavich *et al.* 2000). Habitat edges have been identified as preferred habitats for other fishes, with more abundant (O'Connell and Carlile 1993) and diverse fish assemblages (Friedlander and Parrish 1998). Habitat edges may provide complex structure because of the dramatic change in vertical relief from the soft seafloor substrata to rocky habitat. As patches become larger, the ratio of patch perimeter to patch area decreases, resulting in fewer patch edges (McIntyre and Wiens 1999). Macro-scale habitats may be the most appropriate scale to represent this ratio between patch size and patch edges.

In contrast, *S. mystinus* and *O. elongatus* were found primarily on one seafloor type. Rock and sand mixed patches can be viewed as habitat edges or interfaces between high relief rocky substrates and low relief nonlithofied sediments. For *S. mystinus*, logistic regression predicted it to occur over organic (understory algae) and rock patches in shallow water and would be absent on coarse grain hash patches. IHE results do not concur with the logistic regression model. There were some seafloor types (Boulder-boulder, Boulder-hash, Boulder-organic, Boulder-sand, Hash-cobble, Organic-hash, Rock-boulder, Rock-organic, and Rock-rock) with very high IHE values but were not significant factors in the logistic regression. The IHE values may be artificially inflated or logistic regression may not reflect habitat availability. These seafloor types were rare and sampled infrequently and only one species occurrence can inflate the IHE value. However, these results agree with previous habitat associations, where *S. mystinus* is described as a schooling, shallow water fish associated with macroalgae canopy (Miller and Geibel 1973). In 1997, strong fall storms removed a majority of the macroalgae canopy, which may explain why *S. mystinus* was found lower in the water column, associated with understory algae and rocky outcrops. Additionally, the multivariate ordination placed *S. mystinus* in a habitat guild with other species (*Oxylebius pictus*, *S. serranoides*, and *S. carnatus*) previously described as occupying the same habitats (Allen 1985; Hallacher and Roberts 1985).

For *Ophiodon elongatus*, logistic regression did not identify any significant associations with specific seafloor types. However, five seafloor types were identified by IHE as high habitat use areas. All of these habitats were rocky substrata with high to moderate complexity. A prior survey describes *O. elongatus* as patchily distributed over rocky and hard seafloor types (Jagielo 1988). *Ophiodon elongatus* may only use habitat as a feeding area and periodically as a spawning site.

In this study, a multivariate ordination analysis identified three habitat guilds based on species and habitat features. Spatially heterogeneous habitat and higher species richness defined one guild, while the other guild was defined by low complexity habitat with only one species. Logistic regression models successfully identified small-scale habitat features for three out of four fish species, and IHE analysis showed habitat use patterns for all four species. *Sebastes mystinus*, *S. semicinctus*, and *S. chlorostictus* are more likely to be present on less available high relief rocky habitat and interfaces between rocky and sandy habitat over the more available unstructured soft sediment habitat. While *Ophiodon elongatus* does not show any significant habitat affinity, it is also found on rocky, moderately complex seafloors. Three out of four species were also found on longer patches, indicating the macro-scale habitats are more appropriate than the micro-scale habitats for assessing habitat associations of these fish species. The results of this research show important fish and habitat associations that will help fishery managers identify and protect essential fish habitat.

Future analyses will continue to assess the habitat use of more species within this sampling area. Nine more species have been selected for analysis and preliminary results have shown similar habitat associations. The 1998 survey data from these locations will be compared to see if habitat associations are temporally stable. The fish and habitat associations will also be compared with 1997 data sampled adjacent to this area to see if these habitat use patterns are consistent across different locations. In addition, the relationship between the habitat edges and patch size will be analyzed to determine the optimal scale for fish habitat assessment.

Figures

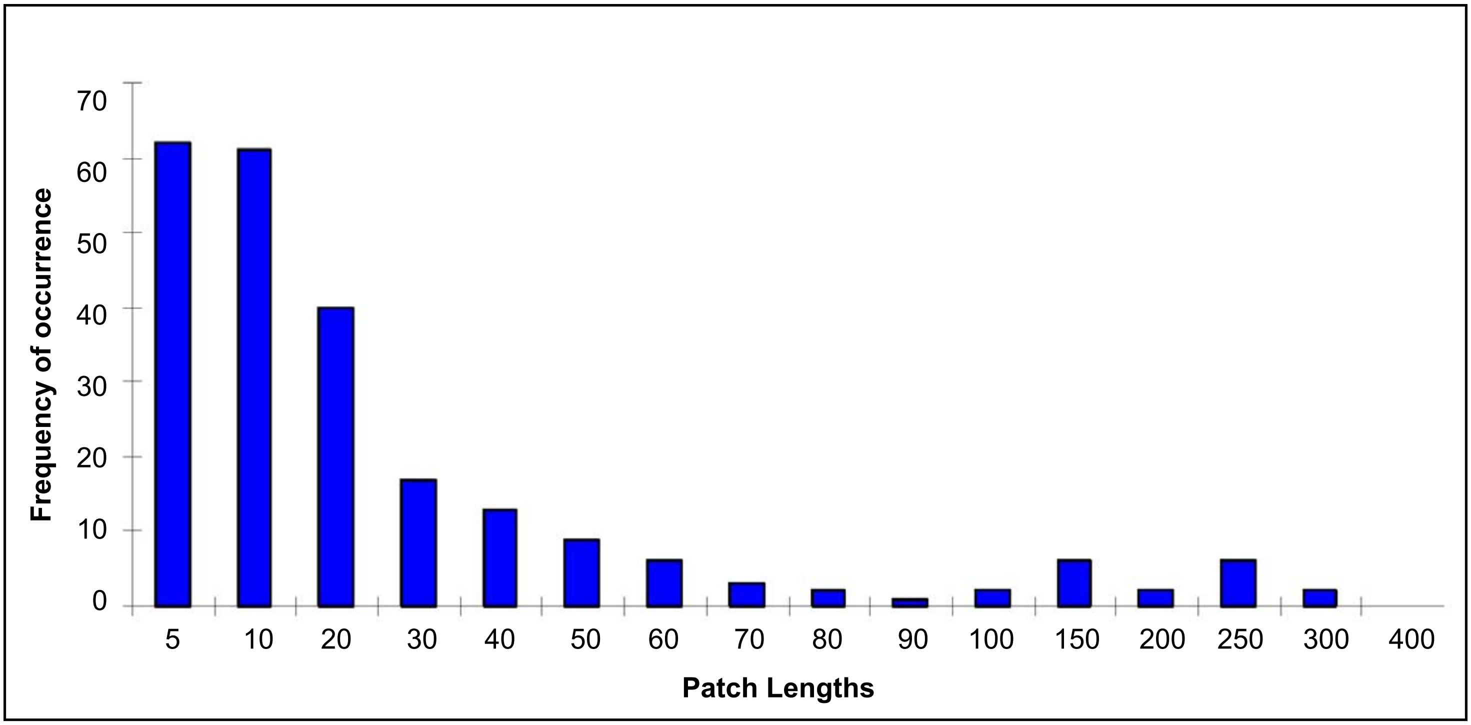

FIGURE 1. Histogram of patch lengths inside and near the Big Creek Ecological Reserve in 1997. A majority of patches were under 30 meters in lengths.

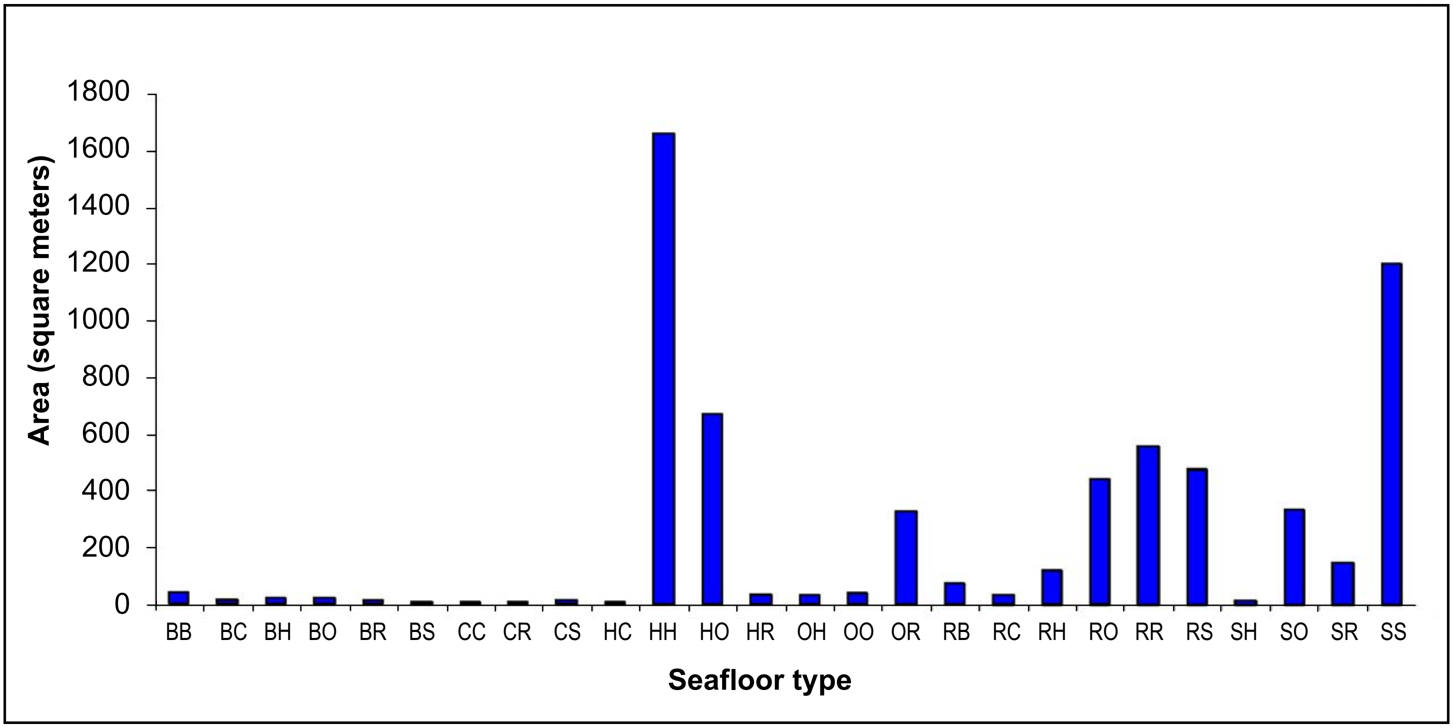

FIGURE 2. A histogram of patch area per seafloor type. BB=Boulder-boulder, BC=Boulder-cobble, BH=Boulder-hash, BO=Boulder-organic, BR=Boulder-rock, BS=Boulder-sand, CC=Cobble-cobble, CR=Cobble-rock, CS=Cobble-sand, HC=Hash-cobble, HH=Hash-hash, HO=Hash-organic, HR=Hash-rock, OH=Organic-hash, OO=Organic-organic, OR=Organic-rock, RB=Rock-boulder, RC=Rock-cobble, RH=Rock-hash, RO=Rock-organic, RR=Rock-rock, RS=Rock-sand, SH=Sand-hash, SO=Sand-organic, SR=Sand-rock, and SS=Sand-sand.

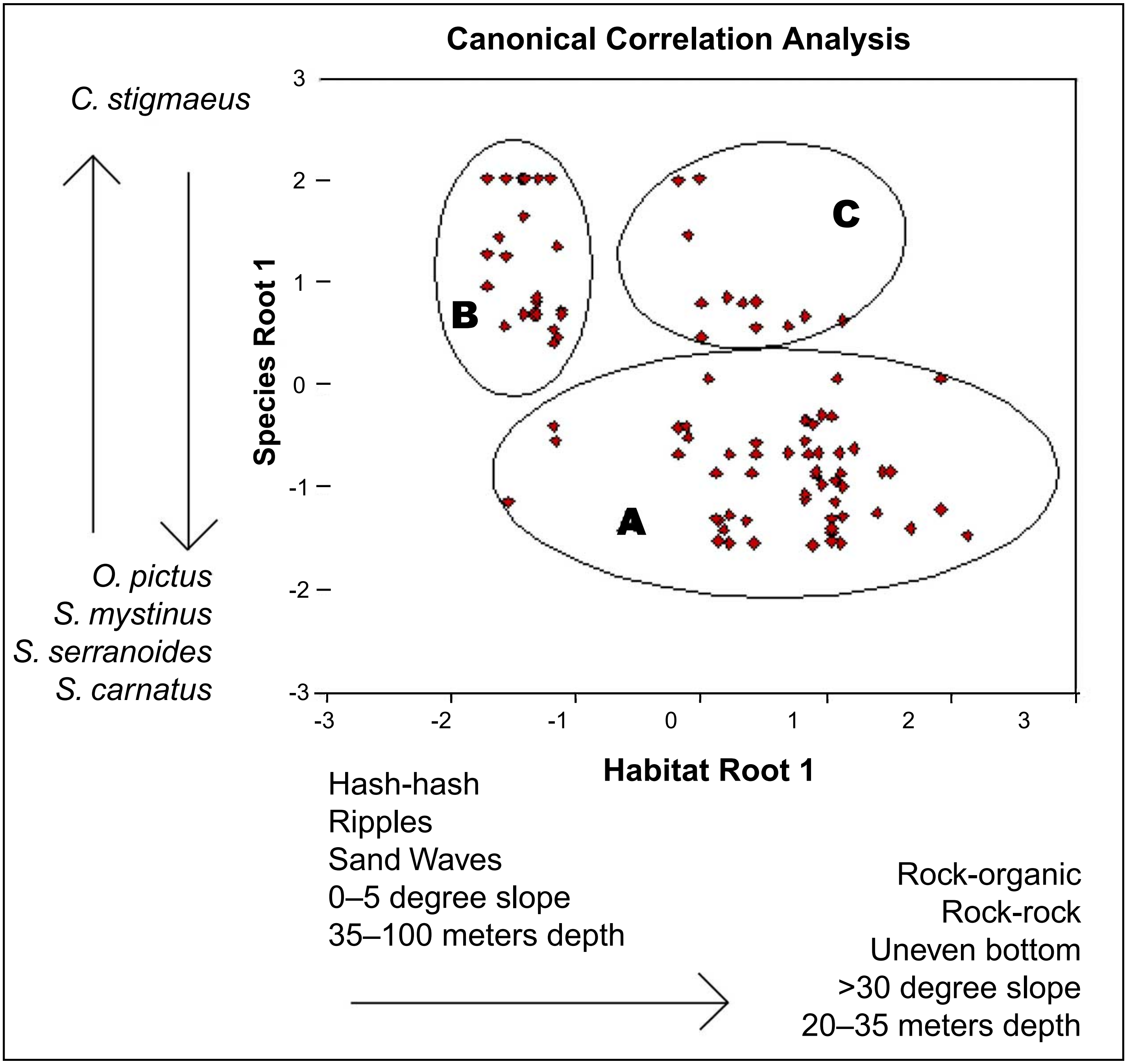

FIGURE 3. Plot of canonical root pairs. Guild A represents shallow water rock habitats with steep slopes inhabited by *O. pictus, S. mystinus, S. serranoides,* and *S. carnatus*. Guild B represents deep water coarse sand seafloor habitats with a flat slope inhabited by *C. stigmaeus.* Guild C represents the interface where sandy and rocky habitats meet, inhabited by *C. stigmaeus, S. mystinus,* and *O. pictus*.

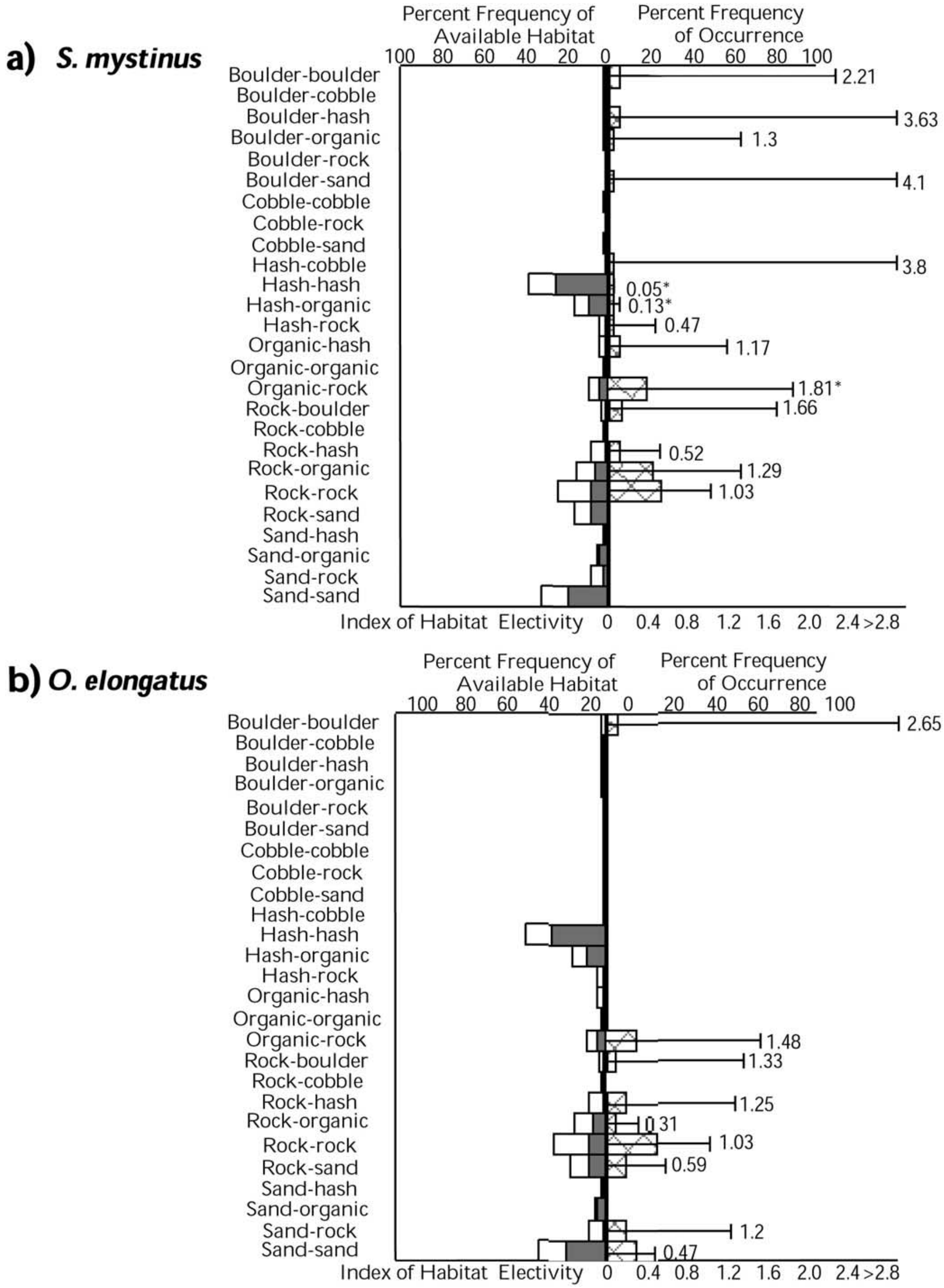

FIGURE 4. Index of Habitat Electivity (IHE) for *Sebastes mystinus* (a) and *Ophiodon elongatus* (b). Available habitat is plotted on the left portion of the graph and is composed of the percent area of each seafloor type (black column) and percent frequency of patch occurrence (white). The percent frequency of occurrence of each species (hatched) and IHE values are plotted on the right portion of the graph with a scale bar. IHE values were marked with an asterisk (*) if that seafloor type was significant using logistic regression. High IHE values (>1.0) indicate habitat electivity.

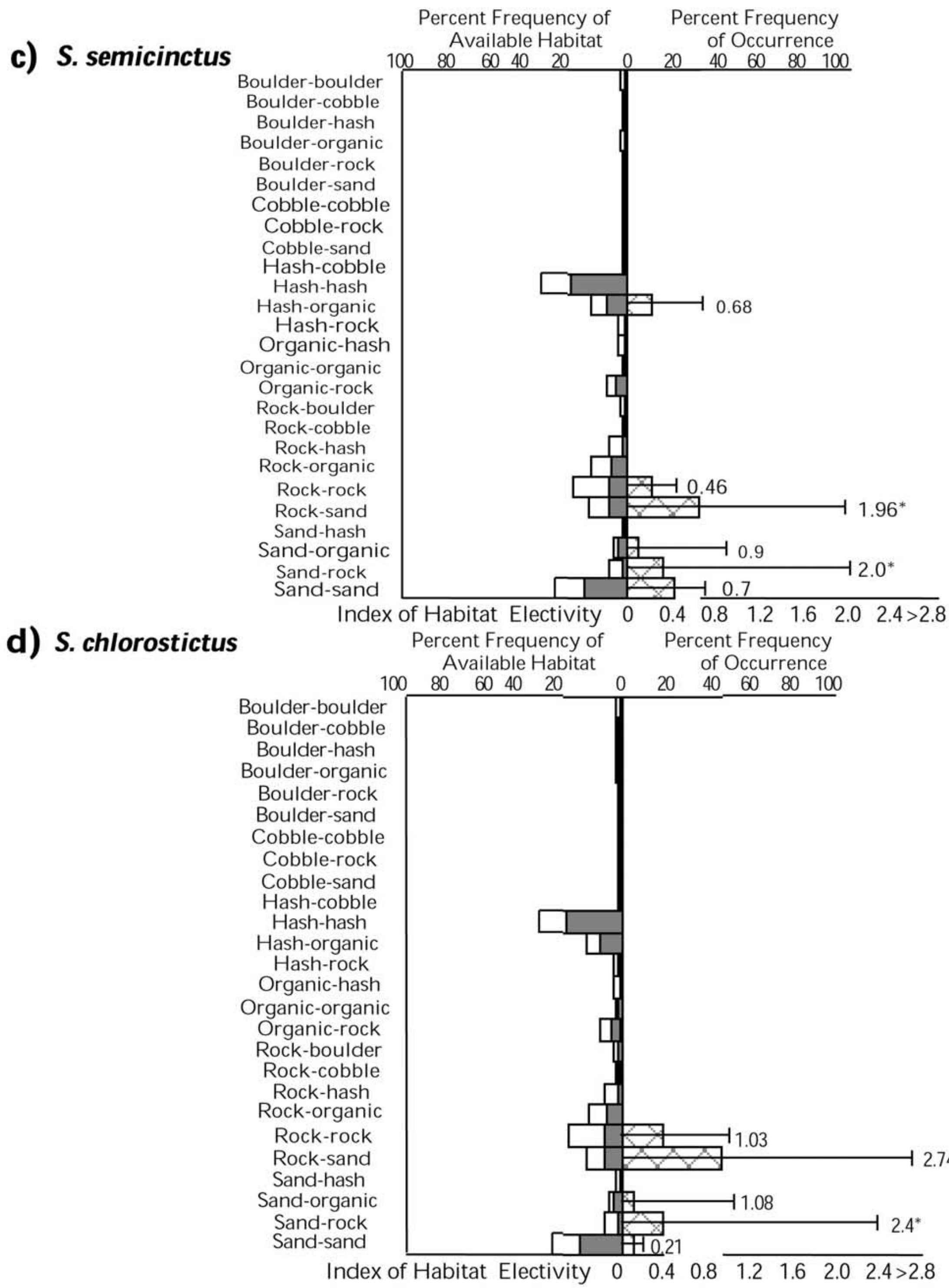

FIGURE 4 continued. Index of Habitat Electivity (IHE) for *Sebastes semicinctus* (c) and *Sebastes chlorostictus* (d). Available habitat is plotted on the left portion of the graph and is composed of the percent area of each seafloor type (black column) and percent frequency of patch occurrence (white). The percent frequency of occurrence of each species (hatched) and IHE values are plotted on the right portion of the graph with a scale bar. IHE values were marked with an asterisk (*) if that seafloor type was significant using logistic regression. High IHE values (>1.0) indicate habitat electivity.

Tables

TABLE 1. A list of the fishes recorded in and near the Big Creek Ecological Reserve in 1997. Species marked with an asterisk (*) were used in the logistic regression and IHE for this report. Species marked with a double asterisk (**) are in the process of being analyzed for a Master of Science thesis at Moss Landing Marine Laboratories. N represents the total number of each taxon observed. FO indicates the frequency of occurrence that each taxon was observed within different seafloor patches.

Scientific Name	Common name	N	FO	Scientific Name	Common name	N	FO
Agonidae	poachers	37	15	*Rathbunella alleni*	stripefin ronquil	1	1
Argentina sialis	Pacific argentine	39	14	*Sebastes atrovirens*	kelp rockfish	6	5
Aulorhynchus flavidus	tubesnout	153	3	*Sebastes carnatus*	gopher rockfish	23	17
Citharichthys sordidus	Pacific sanddab	135	8	*Sebastes caurinus*	copper rockfish	10	8
Citharichthys spp.	sanddabs	264	8	*Sebastes chlorostictus**	greenspotted rockfish	45	15
*Citharichthys stigmaeus***	speckled sanddab	392	29	*Sebastes crameri***	darkblotched rockfish	59	20
Cololabis saira	Pacific saury	200	1	*Sebastes elongatus***	greenstriped rockfish	29	15
*Rhinogobiops nicholsii***	blackeye goby	148	35	*Sebastes entomelas*	widow rockfish	134	4
Cottidae	sculpins	15	10	*Sebastes helvomaculatus*	rosethorn rockfish	48	10
Damalichthys vacca	pile surfperch	20	9	*Sebastes hopkinsi*	squarespot rockfish	459	8
Embiotoca jacksoni	black surfperch	6	4	*Sebastes jordani*	shortbelly rockfish	15	1
Embiotoca lateralis	striped surfperch	16	10	*Sebastes melanops*	black rockfish	1	1
Embiotocidae	surfperches	10	7	*Sebastes miniatus*	vermilion rockfish	11	6
Enophrys taurina	bull sculpin	4	3	*Sebastes miniatus/pinniger*	vermilion/canary complex	152	5
Eptatretus stoutii	Pacific hagfish	2	2	*Sebastes mystinus**	blue rockfish	1181	48
Glytocephalus zacharius	rex sole	1	1	*Sebastes ovalis*	speckled rockfish	2	1
Hexagrammos decagrammus	kelp greenling	9	8	*Sebastes paucispinis*	bocaccio	8	5
Hydrolagus colliei	spotted ratfish	20	2	*Sebastes pinniger*	canary rockfish	6	5
Hypsopsetta guttulata	diamond turbot	1	1	*Sebastes rosaceus***	rosy rockfish	55	14
Icelinus filamentosus	threadfin sculpin	2	1	*Sebastes rosenblatti*	greenblotched rockfish	6	4
Lepidopsetta bilineata	rock sole	2	1	*Sebastes ruberrimus*	yelloweye rockfish	5	3
Lycodes cortezianus	bigfin eelpout	3	1	*Sebastes rufus*	bank rockfish	9	6
Lyopsetta exilis	slender sole	13	9	*Sebastes saxicola***	stripetail rockfish	77	14
Merluccius productus	Pacific hake	129	8		YOY halfbanded rockfish	2236	7
Microstomus pacificus	dover sole	26	9	*Sebastes semicinctus**	halfbanded rockfish	261	18
*Ophiodon elongatus**	lingcod	30	20	*Sebastes serranoides***	olive rockfish	121	31
Oxyjulis californica	señorita	3	2	*Sebastes* spp.	rockfishes	559	45
*Oxylebius pictus***	painted greenling	120	54	*Sebastes* spp. (YOY)	young-of-year rockfishes	8267	64
Phanerodon atripes	sharpnose surfperch	101	2	*Sebastes wilsoni***	pygmy rockfish	376	15
Pisces	unidentified fishes	35	25	*Sebastes zacentrus*	sharpchin rockfish	1	1
Pleuronectiformes	flatfishes	86	23	*Sebastomus spp.*	*Sebastomus* rockfishes	63	24
Parophrys vetulus	English sole	2	2	*Semicossyphus pulcher*	California sheephead	8	6
Pleuronichthys spp.	turbots	3	3	*Zalembius rosaceus*	pink surfperch	36	10
Porichthys notatus	plainfin midshipman	1	1	*Zaniolepis spp.*	combfishes	1	1
Raja spp.	skates	1	1	Zoarcidae	eelpouts	9	4

TABLE 2. Logistic regression coefficients and model significance from the best-fit models for *Sebastes mystinus, S. semicinctus, Ophiodon elongatus, and S. chlorostictus.* Each habitat variable had 1 degree of freedom. Statistically significant ($p<0.05$) bottom types or other variables are in bold type and marked with an asterisk (*). Empty cells indicate a given species did not occur on that bottom type. Cells marked with hash marks (—) indicate bottom types that were removed from the logistic regression model. Negative or positive ß values indicate negative and positive relationships between fish species and habitat features, respectively. The overall model for each species was highly significant ($p<0.000$ for *S. mystinus*; $p<0.018$ for *O. elongatus*; $p<0.001$ for *S. semicinctus*; and $p<0.000$ for *S. chlorostictus*).

	Sebastes mystinus		***Ophiodon elongatus***		***Sebastes semicinctus***		***Sebastes chlorostictus***	
	ß	p value	ß	p value	ß	p value	ß	p value
Seafloor types								
Boulder-boulder	---	---	---	---				
Boulder-hash	6.25	0.691						
Boulder-organic	---	---						
Boulder-sand	---	---						
Hash-cobble	---	---						
Hash-hash	-2.724	**0.009***						
Hash-organic	-2.165	**0.044***			---	---		
Hash-rock	-1.608	0.142						
Organic-hash	---	---						
Organic-rock	1.409	**0.05***	---	---				
Rock-boulder	---	---	---	---				
Rock-hash	---	---	---	---				
Rock-organic	---	---	---	---				
Rock-rock	---	---	---	---	---	---	1.89	0.148
Rock-sand			---	---	2.412	**0.005***	2.529	**0.023***
Sand-organic					---	---	---	---
Sand-rock			---	---	2.759	**0.008***	2.418	**0.05***
Sand-sand			---	---	---	---	---	---
Other variables								
Depth	-0.849	**0.013***	---	---	-0.843	**0.018***	0.597	0.278
Patch length	---	---	0.013	**0.018***	0.014	**0.022***	0.038	**0.011***
Slope			---	---	0.1	**0.043***	7.899	0.828

Part Three

Integrated Maps of Seafloor Habitats and Onshore Geology in the Big Creek Ecological Reserve Area

During a third-year extension of our research on marine habitats of the Big Creek Ecological Reserve (BCER), we synthesized all available data sets relevant to seafloor habitat characterization of the Big Creek area. We combined onshore topography and geology of the BCER area and our offshore geologic and habitat maps to form seamless regional land (coastal)-offshore mega- and mesohabitat maps. For this extension of our MERRP project, we had four objectives:

1. To compile existing data of bathymetry and interpretative maps of seafloor habitats for the entire BCER and adjacent areas. These data were collected separately in two different MERRP projects (i.e., D. VenTresca et al. and our own);
2. To acquire and digitize topographic data and geologic interpretations of the area onshore of BCER study site;
3. To combine all data from objectives 1 and 2 into one comprehensive Geographic Information System (GIS);
4. To provide accurate integrated maps (digital and paper) of seafloor habitats and related geology within the entire study area (shallow and deep areas of BCER and onshore terrestrial areas).

Methods

Various sources of digital and paper (hardcopy) data were used to develop maps that integrate benthic marine habitats and onshore geology of the BCER and adjacent areas. Four main data sets have been identified, relating to (a) Terrestrial, (b) Shallow-Water (<25 m), (c) Mid-depth (25–200 m), and (d) Deep-Water (>200 m) zones. These sets include gridded elevation data and elevation contours of adjacent onshore areas, digitally processed sidescan sonar imagery and interpretation for shallow and mid-depth zones, gridded bathymetry and depth contours for all depth zones, and multibeam sunshaded imagery in deep water. These data were acquired from Monterey Bay Aquarium Research Institute; U.S. Geological Survey; California State University, Monterey Bay; University of Kansas; California Department of Fish and Game; National

Marine Fisheries Service; and Moss Landing Marine Laboratories. These data have been processed and merged into one compatible GIS, and are now in an ArcView®-ready format. From these data sets, new marine habitat and geology interpretations were made and a 3-D model of these data was created. A preliminary virtual “fly-through” has been developed using this 3-D model. Details of GIS development and data layers are given below.

Terrestrial Data

The Terrestrial data set comprises elevation contours, a Digital Elevation Model, and Satellite Landsat imagery acquired from www.usgs.gov, vegetation habitat interpretation polygons from P. Rich (Department of Ecology and Evolutionary Biology, University of Kansas), stream and river vectors, and geology units (polygons) and geologic structure vectors from Hall (1991). Data were acquired and reprojected into Universal Tranverse Mercator, WGS 84, zone 10 using TNT Mips® GIS software. The satellite imagery was combined into a RGB raster using the TM 5,4,3 satellite images. All data files were converted and exported to ArcView® format. All geologic contacts and structure displayed on this map were traced onto a mylar sheet, which was georeferenced from the basemap. The map extents (SE: 36°00′00″ N × 121°30′00″ W; SW: 36°00′00″ N 121°39′45′ W; NW: 36°08′00′ N × 121°39′45″ W; NE: 36°08′00″ N × 121°30′00″ W) estimate the boundaries of the Landels-Hill Big Creek Ecological Reserve. A digital file (bc_units) contains information necessary for map construction (e.g.: scale: 1: 24,000, projection: polyconic). All linework on the transcribed map was digitized and edited using ALACARTE, a menu-driven interface for ArcInfo® that was developed by the U.S. Geological Survey). During the editing process, it became apparent that the original basemap was not properly georeferenced. A tic-coverage with the properly georeferenced map extents was created in ArcInfo® and the edited file was copied to this new tic-coverage. The file was reprojected into UTM (Universal Transverse Mercator) zone 10, WGS (World Geodetic System) 84, the projection and spheroid chosen for this project. The resulting file (bc_units_utm) was copied, creating two identical files with all relevant linework from the mylar sheet. Polygon topology was ascribed to one file (bc_units_utm) and line topology to the other (bc_contacts_utm), using the “clean” command in ALACARTE. The file bc_contacts_utm was recopied and saved as bc_geology_utm for later use in constructing a structural geology layer.

All unnecessary linework was deleted from the polygon file, leaving only lines defining geologic unit contacts. Polygons were tagged with appropriate labels denoting their geologic composition (Table 1) and the layer was built for polygon topology. The same procedure was performed on the line file, which also was processed for line topology. The resulting files (bc_units_utm and bc_contacts_utm) were imported into ArcView® and converted to shape files (bc_units_utm.shp and bc_contacts_utm.shp). Appropriate line weights and colors were chosen for the contact lines using the default ArcView® palette and saved in a legend (contacts.avl). Polygon colors were based on Hall (1991) and saved to a different legend (geo_units.avl).

All unnecessary linework was deleted from the file bc_geology_utm, leaving only lines denoting geologic structure. These lines were attributed as anticline, inferred; anticline, certain; thrust fault, inferred; thrust fault, certain; thrust fault, concealed; fault, inferred; fault, certain; fault, concealed; and syncline, inferred, based on Hall (1991). A file was created for each line type by deleting all other line types and saving the edited layer. These layers were again built for line topology using the "clean" command in ALACARTE. The resulting files were imported into ArcView®. Appropriate line weights and colors were chosen for the different line types using the default ArcView® palette and the geology ArcView® palette and saved in legend files (.avl) corresponding to each line type. Thrust fault teeth were displayed in an irregular manner because they are automatically assigned to lines based on the number and spacing of line vertices. This problem was corrected using the "genfeat" script associated with ArcView®, which removes unnecessary vertices from lines. Because this feature necessitated that all thrust fault symbols be uniform, additional files containing linework for inferred, concealed, and certain thrust faults were added (thrust fault direction1.shp, thrust fault direction2.shp, and thrust fault direction3.shp). Lines of each type were attributed with distinct colors so that they could be distinguished after adding thrust fault symbols. All files comprising this project were saved to the project file bc_geology2.apr.

Shallow-water Data

The Shallow-water data set comprises a mosaic of sidescan sonar imagery, bathymetric soundings, bathymetric depth contour vectors, habitat polygons interpreted from the sidescan sonar imagery, and scuba groundtruthing videos linked to dive site location vectors. All of these data were acquired by D. VenTresca (California Department of Fish and Game) during MERRP research project 8-BC-N. The shallow-water soundings file was merged with the mid-water soundings file into *soundings_utm* shapefile. The habitat polygons were renamed to coincide with the mid-water habitat polygons; that is, "Boulder/Rock" designation was changed to "Boulder," "Rock Flat/Fracture" was changed to "Rock Outcrop," and the "Rock Outcrop" was changed to "Pinnacles/Isolated Boulders." Dive videos were edited into short (15 seconds) segments of longer transects that were conducted in 1998 during fishes and habitat surveys; these video segments were converted into .avi files.

Mid-depth Data

The Mid-depth data set comprises a mosaic of sidescan sonar imagery, bathymetric soundings, bathymetric depth contour vectors, habitat polygons interpreted from the sidescan sonar imagery, and scuba groundtruthing videos linked to dive site location vectors. Sidescan sonar imagery was acquired during a previous research cruise (see Yoklavich et al. 1997). A hard copy, hand-mosaic image was scanned at 600 dpi into 4 sections. Each section was georeferenced and combined in TNT Mips® to create one continuous raster image. This file was reprojected into UTM, zone 10, WGS 84, and converted and exported in ArcView® format. The raw sidescan sonar data also were re-processed using Triton Elics ISIS and DelphMap®, creating 15 georeferenced survey lines. These were mosaicked using TNT Mips, and converted and exported in ArcView“ format (*ISIS_sssutm.tif*).

The Mid-depth habitat polygons (see Yoklavich et al. 1997 and Part One of this report for description) originally were created in MapGraphix® as CAD (.dxf) files, and subsequently converted and imported into TNT Mips® as vector objects. Vector objects were added successively to a master layer using the “combine” or “merge” function. This master layer was filtered to remove polygon slivers that were created in the merging and combing processes. The final filtered layer was exported as an ArcView® shapefile (.shp) and re-projected from UTM projection, zone 10, and NAD 83 datum to UTM projection, zone 10, WGS 84 datum. The habitat shapefile was edited in ArcView® so those adjacent polygons would share a single border. A more general classification scheme (named “substrate”) was created and added in the attribute table. This field combined the original file-name convention into eight types: Boulder field, Coarse Sediment, Fine Sediment, Rock/Sediment Mix, Ripples, Rock Outcrop, Sand, and Isolated Pinnacle/Boulder.

A .dxf file of depth contours was created in Surfer, and converted and imported as a vector file (*mid_cont_rough.shp*). It was re-projected into UTM, zone 10, WGS 84 processed to clean up extraneous vectors and text (*Mid_10mcontours.shp*). Each line was then tagged with the appropriate depth value to create a new .dbf file associated with the vector file. The bathymetric soundings were.txt format that was converted to .csv and imported as .shp file (Mcarthur.shp). The file was edited to remove erroneous points then re-projected into UTM, zone 10, WGS 84.

Deep-water Data

The Deep-water data set comprises sunshaded bathymetric imagery, contoured bathymetic vectors, gridded bathymetry ArcInfo® data, and ArcInfo® coverage themes, which were all acquired from high-resolution Simrad EM300 (30 kHz) multibeam swath bathymetry that was collected recently by H. G. Greene and others from the Monterey Bay Aquarium Research Institute. These excellent EM300 data provide detailed information related to seafloor habitats in the deepwater parts of our study area and present a regional perspective not otherwise readily available. Sunshaded imagery extended offshore from the shelf break and was printed at 1:22,000 scale with UTM gridlines. Deep-water benthic geologic morphology was interpreted from this base map. Extents of the map encompassed the interpreted area:

(SE: 36°00′03.9″ N × 121°34′47.3″ W; SW: 36°00′10.1″ N × 121°44′06.4″ W; NW: 36°09′21.8″ N × 121°43′57.6″ W; NE: 36°09′15.5″ N × 121°34′37.4″ W) and were converted from UTM to geographic coordinates for use in ALACARTE. A digital file (bcoffshore) contains information on map construction (e.g.: scale: 1: 22,000, projection: none). All linework on the transcribed map was digitized using ALACARTE. Polygon attributes were added and the resulting coverage was "cleaned" for polygon topology. The file was reprojected into UTM zone 10, WGS 84. A tic-coverage with the properly georeferenced map extents was created in ArcInfo® and the digitized file was copied to this new tic-coverage to rectify an input error in the original base map. The resultant file (still termed bcoffshore) was imported into ArcView® and converted to a shapefile (bcoffshore.shp). Contact line weight and polygon colors were saved in a legend file (bcoff.avl). The project files were saved in the project bc_offshore.apr. This file was rectified using the sunshaded image and renamed bcoffshore_5-15.shp.

Three-Dimensional Models and Simulations

Three-dimensional surface models were created for the Terrestrial, Shallow-water, Mid-water, and Deep-water data sets. Imagery was draped over the models and flight simulations were created. The *DEM* was used as a surface model for the Terrestrial data set. The *RGB 543* image was draped over this model along with the *streams_wgs84* vector file. All layers are in UTM WGS 84, zone 10. A flight simulation video was created (*Terr_crkshr_BCER.mpg*) with a constant flight elevation of 200 m (relative to DEM). Simulation flight speed is 250 m/s, with 50 frames/s and 15 frames per grouping. Frame width is 320 cells and frame height is 240 cells. The simulation begins with a northern bearing and turns 90° west. For the Shallow-water data set, the *soundings_utm* file was processed and converted into a Triangulated Irregular Network (TIN) model using the Delaunay method in TNT Mips® surface modeling function. This TIN model was processed and converted into a 32-bit floating point, 8.06063 m cell size DEM using the Triangulation method in TNT Mips® surface modeling function. This DEM was used as a surface model and the sidescan sonar images (*sssshallowutm_North.tif*, *sssshallowutm_south.tif*) and coastline vector (*coastWGS84.shp*) were draped over it. A flight simulation video was created (*Shllw&shr_BCER.mpg*) with a constant flight elevation of 200 m above sea level and a northern bearing. Simulation flight speed is 250 m/s, with 50 frames/s and 15 frames per grouping (frame width:320 cells; frame height: 240 cells).

To create a more dense set of bathymetric soundings, the Mid-depth data set soundings were combined with soundings acquired from National Oceanographic Data Center. For the Shallow-water data set, the *soundings_utm* file was processed and converted into a TIN model using the Delaunay method in TNT Mips® surface modeling function. This TIN model was processed and converted into a 32-bit floating point, 8.06063 m cell size DEM using the Triangulation method in TNT Mips® surface modeling function. This DEM was used as a surface model and the sidescan sonar image (*ISIS_sssutm.tif*) was draped over it. A flight simulation video was created (*Midsss_BCER.mpg*) with a constant flight elevation of 200 m above sea level and a northern bearing. Simulation flight speed is 250 m/s, with 50 frames/s and 15 frames per grouping (frame width: 320 cells; frame height: 240 cells). All 3-D flight simulations were saved as .avi files.

Results and Products

Digital and analog maps and 3-D models* of bathymetry, topography, interpretive seafloor habitats and geology within and surrounding BCER have been developed. and included in this report on the second CD-ROM. The maps were created in TNT Mips®, as described in the Methods section and comprise:

1. Map of Marine Bathymetry and Elevation Contours of BCER and Adjacent Areas, which includes onshore elevation at 30-m intervals, nearshore and mid-depth bathymetry at 20-m intervals, and deep water multibeam bathymetry at 100-m intervals.
2. Map of Marine and Terrestrial Imagery of the BCER and Adjacent Areas, which includes Landsat TM Imagery, streams, sidescan sonar imagery of shallow and mid-depth marine areas, and deep water multibeam sunshaded imagery.
3. Map of Marine Benthic Habitats and Terrestrial Geology of BCER and Adjacent Areas, which includes terrestrial geology units, interpretation of shallow and mid-depth marine benthic habitats, and deep water multibeam sunshaded imagery and interpreted geologic morphology.

These products will be useful in evaluating the reserve's effectiveness at maintaining and enhancing coastal fishery species, and should generally improve the conceptual design and models for fishery reserves. These products will serve as a baseline from which physical change to essential fishery habitats can be monitored. It will also serve as a comprehensive basemap onto which other georeferenced data sets (e.g., kelp cover, faunal distributions, and ocean circulation) can be appended.

The ability to combine high resolution views of marine and terrestrial habitats in a virtual 3-D environment will serve to enhance our understanding of how coastal habitat patterns and processes are coupled. For example, marine habitats can be transient and dependent on geological and physical processes that occur not only on the continental shelf where BCER is located but also on land and along the continental slope. Earthquakes and fault

*Given the size limitations of this CD publication, the 3-D models mentioned above have been excluded. The 3-D simulations and ancillary data may be available upon request from the principal investigator.

ruptures can cause landslides in the coastal cliffs that can travel offshore to bury marine habitats or create mass wasting along the continental slope that can carry habitats away. Severe storms can heavily erode cliffs and transport sediment offshore to cover critical habitats. Identifying past and potential sites of erosion and mass wasting will help us determine the history (e.g., the longevity and modifications) of marine habitats. This approach will enable the user to more intuitively identify relationships between geologic patterns observed onshore and the offshore expression of these patterns as benthic marine habitat types supporting distinct biotic communities. Development of these comprehensive maps of benthic habitat and related geology is critical in understanding the regional processes that influence distributions of fishes in the Big Creek region.

These products will be valuable to the long-term site characterization and monitoring goals of both the BCER and the adjacent UC Landels-Hill Big Creek Terrestrial Reserve. These products also directly contribute to our knowledge of the health of the Monterey Bay National Marine Sanctuary's resources, and will be of particular use to the Sanctuary's Integrated Monitoring Network (SIMoN). In addition, the Pacific Fisheries Management Council currently has identified habitat studies of rockfishes, and the effects of fishing on those habitats, as high research priorities. With the reauthorization of the Magnuson Fishery Conservation and Management Act (Sustainable Fisheries Act of 1996), a congressional mandate requires identification and implementation of essential habitat for all federally managed species of fishes (information on habitats in deep water is especially needed). A major rationale of our entire study is to provide information on the relationship of fishes to particular habitats so managers will be able to ensure the continued wise management of valuable resources.

Table

TABLE 1. Explanation of onshore geologic units Marine Benthic Habitats and Terrestrial Geology of the Big Creek Ecological Reserve and Adjacent Areas.

Geologic Units	Explanation
Kjf	Cretaceous-Jurassic Franciscan melange
Ku?	Upper Cretaceous sedimentary rocks; uncertain
Kush	Upper Cretaceous sedimentary rocks; shale unit
Kuss	Upper Cretaceous sedimentary rocks; sandstone unit
Kuss/cg	Upper Creatceous sedimentary rocks; sandstone unit containing conglomerate clasts
Qal	Alluvial deposits
Qc	Landslide and colluvial deposits; loose mass of soil and/or rock fragments
Qls	Landslide and colluvial deposits; rock and mudflow debris
Qs	Dune sand deposits
Qt	Stream and marine terrace deposits
Qt?	Stream and marine terrace deposits; uncertain
bs	Blue schist
cg	Conglomerate
ch	Chert
gr	Granite
gw	Graywacke
gw/sh	Graywacke containing shale
i	Plutonic igneous rocks
m	Metamorphic rocks
ma	Marble
mv	Metavolcanic rocks
s	Serpentinite
sh	Shale
ss	Sandstone
undefined	No data available

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